ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

1935

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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, December 16, 1935.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1935. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

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ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1935

SUBJECTS

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2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1935.

3. General appendix comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1935.

THE SMITHSONIAN INSTITUTION

June 30, 1935

Presiding officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.
JOHN N. GARNER, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
CORDELL HULL, Secretary of State.
HENRY MORGENTHAU, JR., Secretary of the Treasury.
GEORGE H. DERN, Secretary of War.
HOMER S. CUMMINGS, Attorney General.
JAMES A. FARLEY, Postmaster General.
CLAUDE A. SWANSON, Secretary of the Navy.
HAROLD L. ICKES, Secretary of the Interior.
HENRY A. WALLACE, Secretary of Agriculture.
DANIEL C. ROPER, Secretary of Commerce.
FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
JOHN N. GARNER, Vice President of the United States.
JOSEPH T. ROBINSON, Member of the Senate.
M. M. LOGAN, Member of the Senate.
CHARLES L. MCNARY, Member of the Senate.
T. ALAN GOLDSBOROUGH, Member of the House of Representatives.
CHARLES L. GIFFORD, Member of the House of Representatives.
CLARENCE CANNON, Member of the House of Representatives.
FREDERIC A. DELANO, citizen of Washington, D. C. (reappointment pending).
JOHN C. MERRIAM, citizen of Washington, D. C.
R. WALTON MOORE, citizen of Virginia.
ROBERT W. BINGHAM, citizen of Kentucky.
AUGUSTUS P. LORING, citizen of Massachusetts.

Executive committee.—FREDERIC A. DELANO, JOHN C. MERRIAM, R. WALTON MOORE.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Personnel officer.—HELEN A. OLMSTED.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.

Assistant Secretary (in charge).—ALEXANDER WETMORE.

Associate Director.—JOHN E. GRAF.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Walter Hough, head curator; W. H. Egberts, chief preparator.

Division of Ethnology: Walter Hough, curator; H. W. Krieger, curator; H. B. Collins, Jr., assistant curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; F. M. Setzler, assistant curator; R. G. Paine, aide; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, assistant curator.

Collaborator in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

DEPARTMENT OF BIOLOGY:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; A. J. Poole, scientific aide; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: George S. Myers, asistant curator; E. D. Reid, aide.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Orthoptera: A. N. Caudell, custodian.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aide; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; William H. Longley, collaborator; Maynard M. Metcalf, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Joseph P. E. Morrison, senior scientific aide; Mary Breen, collaborator.

Section of Helminthological Collections: Maurice C. Hall, custodian.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): Frederick V. Coville, honorary curator; W. R. Maxon, associate curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aide; Egbert H. Walker, aide; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

DEPARTMENT OF BIOLOGY—Continued.

Division of Plants—Continued.

Section of Grasses: Albert S. Hitchcock, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Associates in Zoology: C. Hart Merriam, W. L. Abbott, Mary J. Rathbun, C. W. Stiles, Theodore S. Palmer, William B. Marshall.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator.

Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator.

Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Jessie G. Beach, aide; Margaret W. Moodey, aide for Springer collection.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associates in Paleontology: E. O. Ulrich, August F. Foerste.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ARTS AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.

Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C. Reed, scientific aide.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mineral Technology: Carl W. Mitman, in charge; Chester G. Gilbert, honorary curator.

Division of Textiles: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aide.

Section of Wood Technology: William N. Watkins, assistant curator.

Section of Organic Chemistry: Aida M. Doyle, aide.

Division of Medicine: Charles Whitebread, assistant curator.

Division of Graphic Arts: R. P. Tolman, curator; C. Allen Sherwin, scientific aide.

Section of Photography: A. J. Olmsted, assistant curator.

Loeb Collection of Chemical Types: Aida M. Doyle, in charge.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.

Assistant chief of correspondence and documents.—L. E. COMMERFORD.

Superintendent of buildings and labor.—J. S. GOLDSMITH.

Assistant superintendent of buildings and labor.—R. H. TREMBLY.

Editor.—PAUL H. OEHSER.

Engineer.—C. R. Denmark.
Accountant and auditor.—N. W. Dorsey.
Photographer.—A. J. Olmsted.
Property clerk.—W. A. Knowles.
Assistant Librarian.—Leila F. Clark.

NATIONAL GALLERY OF ART

Acting director.—Ruel P. Tolman.

FREER GALLERY OF ART

Curator.—John Ellerton Lodge.
Associate curator.—Carl Whiting Bishop.
Assistant curator.—Grace Dunham Guest.
Associate.—Katharine Nash Rhoades.
Assistant.—Archibald G. Wenley.
Superintendent.—John Bundy.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—Matthew W. Stirling.
Ethnologists.—John P. Harrington, John N. B. Hewitt, Truman Michelson, John R. Swanton, William D. Strong.
Archeologist.—Frank H. H. Roberts, Jr.
Editor.—Stanley Searles.
Librarian.—Ella Leary.
Illustrator.—Edwin G. Cassedy.

INTERNATIONAL EXCHANGES

Secretary (in charge).—Charles G. Abbot.
Chief Clerk.—Coates W. Shoemaker.

NATIONAL ZOOLOGICAL PARK

Director.—William M. Mann.
Assistant Director.—Ernest P. Walker.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Assistant director.—Loyal B. Aldrich.
Research assistant.—Frederick E. Fowle, Jr.
Associate research assistant.—William H. Hoover.

DIVISION OF RADIATION AND ORGANISMS

Director.—Charles G. Abbot.
Assistant director.—Earl S. Johnston.
Associate research assistant.—Edward D. McAlister.
Assistant in radiation research.—Leland B. Clark.
Research associate.—Florence E. Meier.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1935

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1935. The first 12 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 10 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian Library, and of the publications issued under the direction of the Institution. On page 81 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

Despite the continued curtailment of funds available for the Institution's work, notably the drastic reduction in appropriations for printing the scientific series normally issued by the National Museum and the Bureau of American Ethnology, marked progress has been made along several lines. Study of periodicities in the weather, related to similar periodicities found in the variation of the solar radiation, has progressed to the point where test weather forecasts have been made for 30 stations in the United States for the years 1934, 1935, and 1936. The forecasts for 1934 gave satisfactory agreement with the actual weather conditions for about two-thirds of the stations. Reductions of the solar observations for a year at the new Mount St. Katherine station indicate that they will be quite as excellent and numerous as those of the best Smithsonian station at Montezuma, Chile. John A. Roebling has generously provided funds for the continued occupation of Mount St. Katherine till 1938.

Special attention was given to the problem of the so-called Folsom man, a people associated with the earliest known phase of aboriginal

American culture. In Colorado a Smithsonian expedition unearthed for the first time a variety of implements belonging to that culture, including many of the typical Folsom points. A number of these implements were found in direct association with bones of an extinct form of bison. Further work at this site was under way at the close of the year.

An allotment of $680,000 from the Public Works Administration was made for the erection of three much-needed buildings at the National Zoological Park. The Walter Rathbone Bacon traveling scholarship was awarded to Dr. Richard E. Blackwelder for an intensive study of the staphylinid beetles of the West Indies. The seventh award of the Langley Medal was made to Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, for his outstanding work in connection with the scientific development of aviation in America. In the Division of Radiation and Organisms experiments were carried through relating to the growth of tomato plants under controlled conditions of temperature, humidity, and radiation; the growth of wheat out-of-doors with controlled quantities of carbon dioxide; and the dependence of the growth of wheat and of algae on the wave lengths of radiation.

Among the year's publications may be mentioned Dr. Strong's account of the results of his archeological expedition to the Bay Islands, Spanish Honduras; Dr. Roberts' paper on his investigations of Folsom man; and the second in the Freer Gallery's series of Oriental Studies, "A Descriptive and Illustrated Catalogue of Miniature Paintings of the Jaina Kalpasūtra as Executed in the Early Western Indian Style", by W. Norman Brown, with 45 full-tone plates.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—The appropriations for the year totaled $716,071, an increase of $61,200 over last year. New specimens added to the collections numbered 296,468. These included anthropological material representing many of the North and South American Indian tribes, large collections of natural-history specimens resulting from field work in Brazil by Dr. Doris Cochran and from a third Hancock expedition to the Galapagos Islands participated in by Dr. W. L. Schmitt, biological specimens from Siam and China sent by Dr. Hugh M. Smith and Dr. D. C. Graham, a valuable collection of Paleozoic fossils presented by Edward N. Hurlburt, of Rochester, N. Y., and nearly 50,000 plant specimens from various sources. To the industrial series were added the motorless sailplane *Falcon* (1934), the cup presented to the winner of the first Vanderbilt automobile race 30 years ago, several interesting

ship and locomotive models, and a complete Mergenthaler linotype (no. 9). Field work, though greatly limited from lack of funds, was carried on chiefly through the cooperation and generosity of outside individuals, through grants from the Smithsonian Institution, and through assistance from the P. W. A. It will be described in detail in the special report of the Museum in Appendix 1. Visitors to the several Museum buildings during the year totaled 1,841,306. Under the auspices of various educational, scientific, or Government agencies, 17 special exhibits were held during the year in the foyer of the National Museum.

National Gallery of Art.—Seven special exhibitions were held during the year, representing the work of Clayton Knight, Alexander Trowbridge, Emil Jacques, William Woollett, Elena and Bertha de Hellebranth, Howard Fremont Stratton, and the artists enrolled in the Civilian Conservation Corps camps. A number of art works were accessioned subject to transfer to the Gallery if approved by the National Gallery of Art Commission. Under the Catherine Walden Myer fund, two early American miniatures were purchased for the Gallery. The fourteenth annual meeting of the National Gallery of Art Commission was held on December 11, 1934.

Freer Gallery of Art.—The year's additions to the collection include Chinese bronzes, jade, and ceramics, Syrian glass, Arabic and Persian manuscripts, Chinese, Indian, and Persian paintings, Persian silver, and Arabic wood-carving. Curatorial work was devoted to the study of Chinese, Japanese, Armenian, Arabic, and Persian objects, and of the texts and seals associated with them. During the year 1,268 objects and 153 photographs of objects were submitted to the curator for an opinion as to their identity, meaning, or historical or esthetic value. Visitors totaled 130,346, and 78 groups were given docent service. The special exhibition of Whistler's work installed on May 14, 1934, in honor of the Whistler Centenary, was taken down on December 26.

Bureau of American Ethnology.—Systematic researches conducted by members of the Bureau staff included investigation of finds of the eastern type of Folsom points in Virginia, inspection of mound excavations near Macon, Ga., examination of archeological sites in Georgia and Florida, researches on the ethnology of the Indians of California and other related western Indians, and extensive study and publication on the problem of Folsom man, based on explorations at the Lindenmeier site, Colorado. Linguistic studies were conducted on several Indian languages, including Timucua, Natick, and Algonquian. Further researches were carried on relating to the League of the Iroquois, and a number of Indian songs were recorded

at the Century of Progress Exposition. Extensive reports were published on the archeology of Nebraska and of the Bay Islands of Spanish Honduras.

International Exchanges.—In the official exchange with other countries of governmental and scientific documents, the exchange service handled during the year a total of 654,131 packages, weighing 560,381 pounds. There are now 111 full and partial sets of governmental documents and 102 copies of the daily issue of the Congressional Record sent to foreign depositories.

National Zoological Park.—Accessions to the collection during the year numbered 627, and removals through various causes totaled 695, leaving the collections at the close of the year at 2,170 animals, representing 665 different species of mammals, birds, reptiles, and other forms. The number of visitors was 2,046,149, including groups from 394 schools in 20 States and the District of Columbia. An allotment of $680,000 was made on January 26, 1935, by the Public Works Administration for the construction of a small mammal house, a pachyderm house, an addition to the bird house, and mechanical shops, buildings that have been urgently needed for many years. Work was immediately started on the plans and specifications in the office of the Supervising Architect, with Edwin H. Clarke as consulting architect. Much work was also done on the buildings and grounds with labor and materials supplied by the Emergency Works Administration. The greatest need of the Zoo is for more liberal appropriations for the purchase of specimens.

Astrophysical Observatory.—Regular observations of the solar constant of radiation have been continued daily at the three solar observing stations at Table Mountain, Calif.; Montezuma, Chile; and Mount St. Katherine, Egypt. The observations from Mount St. Katherine have been reduced at the central station at Washington under the direction of the assistant director, L. B. Aldrich, assisted by a special staff of computers made available under a grant from John A. Roebling. The results indicate that this station, established in 1934, will prove to be one of high excellence. Analysis of solar variation since 1920 has revealed 12 periodicities, all aliquot parts of 23 years. These periodicities are also found in temperature and precipitation records for six terrestrial stations for the past century, and the 23-year cycle is found in the levels of lakes and streams, the widths of tree-rings, the catches of ocean fish, varves of Pleistocene and Eocene geologic age, and other phenomena depending on weather. Forecasts of temperature and precipitation for 1934, 1935, and 1936 for over 30 stations in the United States have been made, and satisfactory agreement between forecasts and the events have been found for two-thirds of the stations during 1934.

Division of Radiation and Organisms.—The following investigations were undertaken by the scientific staff of the Division: The dependence of the growth of algae and wheat on the wave lengths of radiation, determined by experiments conducted with Christiansen filters specially adapted to this work by improvements made in the Division; growth experiments on tomato plants under control as to temperature, humidity, and color and intensity of radiation; experiments in cooperation with the United States Department of Agriculture on the promotion and inhibition of the germination of seeds under different selected wave lengths of light; and an experiment on the growth of wheat under out-of-door conditions with controlled quantities of carbon dioxide. Several papers embodying the results of these investigations were published during the year in the Smithsonian Miscellaneous Collections, and others were in preparation.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three Members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of them of the same State." One of the regents is elected chancellor of the board. In the past the selection has fallen upon the Vice President or the Chief Justice, and a suitable person is chosen by the regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

Changes in the personnel of the Board during the year included the appointment on January 23, 1935, of Senator Charles L. McNary, of Oregon, as a regent to succeed Senator David A. Reed, whose term

as a Senator expired January 3, 1935; and the appointment by the Speaker on February 21, 1935, of Representative Clarence Cannon, of Missouri, to fill out the unexpired term to December 25, 1935, of Representative E. H. Crump, whose term as a Representative had expired on January 3, 1935.

The roll of regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—Joseph T. Robinson, M. M. Logan, Charles L. McNary; members from the House of Representatives—T. Alan Goldsborough, Clarence Cannon, Charles L. Gifford; citizen members—Frederic A. Delano, Washington, D. C. (reappointment pending before Congress); John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts.

Proceedings.—Only one meeting of the full Board was held during the year—the annual meeting on January 17, 1935. This date for the annual meeting was fixed by a resolution adopted by the Board on December 14, 1933, naming "the second Thursday following the first Monday in January" thereafter as the date for the annual meeting, on account of the change of the date for the annual convening of Congress to January 3. The regents present were Chief Justice Charles Evans Hughes, chancellor, Senators Joseph T. Robinson and M. M. Logan, Representatives T. Alan Goldsborough and Charles L. Gifford, Frederic A. Delano, Hon. Irwin B. Laughlin, Hon. R. Walton Moore, Augustus P. Loring, Dr. John C. Merriam, and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report, detailing the activities of the several Government branches and of the parent Institution during the year, and Mr. Delano presented the report of the executive committee, covering financial statistics of the Institution. The Secretary also presented the annual report of the National Gallery of Art Commission.

The Secretary presented his usual special report reviewing the outstanding events of the year, and Mr. Delano presented resolutions prepared by the Permanent Committee, calling the attention of the President of the United States to the urgency of grants from the Public Works Administration to carry out the Institution's building program. A resolution was adopted authorizing the transfer of the income of the Loeb fund for a chemical type museum to other purposes in connection with the library of the Chemists' Club of New York City, under certain conditions.

The Board adopted a resolution awarding the Langley Gold Medal for Aerodromics to Dr. Joseph Sweetman Ames.

The meeting then adjourned, and the regents inspected the special exhibits in the Secretary's office illustrative of some of the Institution's recent activities.

FINANCES

A statement will be found in the report of the executive committee, page 81.

MATTERS OF GENERAL INTEREST

CENTENARY OF THE BIRTH OF SAMUEL PIERPONT LANGLEY

On August 22, 1934, the Institution commemorated the one-hundredth anniversary of the birth of Samuel Pierpont Langley, its third Secretary, and one of the foremost American scientists of the nineteenth century. On that date there was issued a pamphlet consisting of extracts from Langley's own writings, in which he described his important discoveries in astronomy, astrophysics, physics, and aeronautics. This pamphlet reveals strikingly the value and breadth of Langley's researches. To the public, his name is best known in connection with his work in aeronautics, but to men of science his fundamental researches in astronomy and physics are of outstanding importance. The titles of some of the papers from which quotations are given in the memorial pamphlet will reveal the scope of his interest: "On the minute structure of the solar photosphere"; "The total solar eclipse of July 29, 1878"; "The bolometer and radiant energy"; "On the amount of atmospheric absorption"; "The temperature of the moon"; "On hitherto unrecognized wave-lengths"; "On a possible variation of the solar radiation and its probable effect on terrestrial temperatures."

A special exhibition was also arranged in the Smithsonian Building of scientific apparatus invented by Langley and of articles associated with him during his lifetime. Outstanding among his inventions was the bolometer, an electrical thermometer capable of detecting a change of heat as little as a millionth of a degree Centigrade.

AWARD OF LANGLEY MEDAL TO JOSEPH S. AMES

The Langley Medal for Aerodromics of the Smithsonian Institution was presented on May 21, 1935, to Dr. Joseph S. Ames, of Johns Hopkins University, Chairman of the National Advisory Committee for Aeronautics, and for years one of the foremost figures associated with the scientific development of American aviation. The presentation was made by Chief Justice Charles E. Hughes, Chancellor of the Institution, in accordance with the award of the Board of Regents at their annual meeting in January. The

award, it was stated in the resolution accompanying the medal, was "in recognition of the surpassing improvement of the performance, efficiency, and safety of American aircraft resulting from the fundamental scientific researches conducted by the National Advisory Committee for Aeronautics under the leadership of Dr. Ames."

He was one of the 12 original members of this committee appointed by President Wilson in 1915. He has served on 20 of its subcommittees and acted as chairman of many of them. He has been executive head of the organization since 1919, during which time it has developed the famous Langley Laboratory, where many airplane improvements now universally in use have been devised.

In accepting the medal, Dr. Ames said:

Mr. CHANCELLOR:

It is with the utmost pleasure that I accept the Langley Medal, and I beg to express to you and your associates my sincere thanks for the great honor paid me. There is no honor in the field of aeronautics as great as this.

When your secretary, Dr. Abbot, informed me that it had been voted to bestow the medal upon me, I was overwhelmed by a feeling of unworthiness. I had not made any contribution of note either to the science or to the art of aeronautics. But I soon realized that the award was not made to me as the result of such services as these, but rather as the result of my connection with the National Advisory Committee for Aeronautics. I think everyone will grant that no single factor has had such a great influence in the notable progress in both theoretical and applied aeronautics in this country during the past 20 years as the National Advisory Committee for Aeronautics, and I am proud to think that your Committee of Award consider me as in some way responsible for the guidance of this work. This point of view I can understand. For I have been a member of the committee since it was established and its executive head for many years. But only I know how far from justified anyone is in attributing the good work of the committee to me. I have simply done my best to make it possible for our scientists and engineers to perform their investigations and to so cooperate with my associates on the committee as to direct its policy wisely.

In recognizing this type of administrative work as of such value as to merit the award of the Langley Medal, I think that your committee, Mr. Chancellor, is not alone justified but also wise, and I am particularly pleased by the fact that this honor comes to our committee while I am its chairman.

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

The Walter Rathbone Bacon traveling scholarship of the Smithsonian Institution was awarded in May 1935 to Dr. Richard E. Blackwelder, at that time engaged in entomological work at the United States National Museum, for an intensive study of the staphylinid beetles of the West Indies. Dr. Blackwelder will collect these beetles, comprising one of the largest and least-known animal families on earth, on 25 West Indian Islands, including Cuba, Hispaniola, Puerto Rico, and Jamaica. Because of the small size

and, as a rule, economic unimportance of this family, it has been much neglected.

The entomologist will make an intensive search for specimens in West Indian anthills. Several species are commensal with ants and, because of this way of life, have developed curious forms. Some of them seem to be kept by the ants as "domestic animals." They are housed, protected, and fed by their hosts because of the body secretion, which is a favorite food of the hosts. Some, on the other hand, seem to live with the ants entirely for the purpose of feeding on them and on their young. Even these are tolerated by their hosts, who apparently have no realization of how they are being victimized.

Staphylinid beetles are also numerous in fungous deposits and in decaying vegetable matter. They remain hidden much of the time, so that little information is available on their habits and life histories. They are found over most of the world. Large collections have been made in Europe and in the United States, and the National Museum has a considerable representation of the different species. The West Indies constitute largely unexplored territory, so far as these beetles are concerned, and it is probable that many new species will be identified from Dr. Blackwelder's collection.

After completing his work in the West Indies, Dr. Blackwelder will study the large collections in the British Museum.

FOURTH ARTHUR LECTURE

Under a bequest received in 1931 from the late James Arthur, of New York City, a lecture is delivered each year at the Institution on some phase of the study of the sun.

The fourth annual Arthur Lecture was given in the auditorium of the National Museum on December 18, 1934, by Dr. Walter S. Adams, director of the Mount Wilson Observatory, on "The Sun as a Typical Star." Dr. Adams, one of the foremost astronomers of the world, has made original researches on the place of the sun among the billions of stars of the galaxy. The lecture will be published in the general appendix to the Smithsonian Report for 1935.

SMITHSONIAN INSTITUTION EXHIBIT AT THE CALIFORNIA PACIFIC INTERNATIONAL EXPOSITION, 1935

The Smithsonian exhibit at the California Pacific International Exposition, which opened at San Diego May 29, 1935, was prepared under the direction of Carl W. Mitman, head curator of arts and industries, National Museum. It is one of a group visualizing activities of the major departments and independent establishments of

the Federal Government. All these exhibits are installed in a newly constructed permanent building simulating an Aztec temple erected in the Exposition grounds. They are distributed over the single floor of the building, the area of which is 170 by 150 feet. The space assigned to the Smithsonian Institution is 38 feet long by 13 feet wide, and is situated along the wide wall to the west or right of the main entrance.

The limited allotment of space and money for the participation of the Smithsonian Institution in the Exposition precluded the preparation of either a general exhibit of all Smithsonian activities or a complete exposition of any single activity. A small exhibit was, therefore, prepared to indicate some of the ethnological work of the Institution in the Southwest.

The space is arranged in the form of a rectangular alcove, the sides of which are exhibition cases 12 feet deep by 9 feet wide. For the rear wall area there was designed a pictorial map of the Southwest, 8 by 6 feet in size. This was painted by Benson B. Moore, of Washington, D. C., in old cartographic style and portrays the journeys of the Spanish explorer, Coronado, in the Southwest in 1540–1543, together with many sites of modern explorations made in this area by the Institution.

According to the historic record of his explorations, Coronado first contacted the Apache Indians and subsequently conquered the Zuñis. In the exhibition cases flanking the map, therefore, there are installed life-size habitat groups of these tribes; the Apache family group of five figures on the left flank and the Zuñi family group of eight figures on the right flank—all dressed in original costumes from the National Museum collections. Landscapes typical of the country in which these tribes live are painted on the closed sides of the cases and form realistic backgrounds for the groups. These paintings were executed by Richmond I. Kelsey, of San Diego, Calif. A descriptive label for each group is mounted on the rear wall in the space between the map and exhibition case. A third label records briefly the Institution's history and activities.

The Exposition was still open at the close of the year and was expected to remain open at least until November 1935.

EXPLORATIONS AND FIELD WORK

Although still considerably hampered in its field operations by lack of funds, the Institution conducted or took part in 20 expeditions, 7 more than in the previous year. Secretary Abbot and his colleagues continued the study of the radiation of the sun, both at Washington and at the three field stations, Table Mountain, Calif., Mount Montezuma, Chile, and Mount St. Katherine, Egypt. Dr.

W. F. Foshag collected minerals and studied mineral deposits in both northern and southern Mexico. Dr. C. Lewis Gazin directed an expedition to collect vertebrate fossils in the Snake River basin of Idaho. Dr. G. A. Cooper established a correlation of middle Devonian deposits in Ontario, New York, and Michigan. Dr. W. L. Schmitt again accompanied the Hancock expedition to the Galápagos Islands. Rev. David C. Graham continued his zoological collecting for the Institution in Szechwan, China. Dr. Hugh M. Smith collected birds, mammals, and other forms in various parts of Siam. Austin H. Clark collected butterflies in Bedford and Princess Anne Counties, Va., in continuation of his survey of the little-known butterfly fauna of Virginia. Jason R. Swallen collected grasses in northeastern Brazil.

Dr. C. W. Bishop, director of the Freer Gallery Field Expedition to China, brought the work to a close in 1934 and returned to the United States. The work of the expedition occupied a period of over 4 years and included the excavation of a number of archeological sites and an archeological reconnaissance of nearly the entire province of Shansi. Dr. Aleš Hrdlička continued his archeological investigations on Kodiak Island, Alaska, unearthing much new evidence on the identity of the ancient inhabitants of the site. H. W. Krieger, through an allotment of P. W. A. funds, excavated archeological sites in Oregon in the area that will be flooded with the completion of the Bonneville Dam. M. W. Stirling supervised several archeological projects in Florida conducted in cooperation with the Federal Emergency Relief Administration. Dr. F. H. H. Roberts, Jr., excavated a camp site and workshop in Colorado attributable to Folsom man, bringing to light for the first time a variety of implements belonging to that early horizon. Dr. Roberts also excavated an extensive Indian site on the former battlefield at Shiloh National Military Park, Tenn. Dr. W. D. Strong conducted archeological excavations at Buena Vista Lake, Calif., and later made a brief archeological reconnaissance of the Cuyama Valley and also of the mountainous district adjacent to the Sisquoc River. W. M. Walker excavated ancient Yokuts shellmounds near Taft, Calif. Dr. J. R. Swanton was successful in further determining points on the route followed by Hernando De Soto in 1540 through Georgia and part of South Carolina. Dr. J. P. Harrington conducted ethnological studies among the Indians of California. Dr. Truman Michelson studied the Passamaquoddy Indians on the State reservation on the coast of Maine.

These expeditions are briefly described and illustrated in the pamphlet entitled "Explorations and Field-Work of the Smithsonian Institution in 1934", Smithsonian publication no. 3300.

PUBLICATIONS

Again this past year the drastic curtailment of printing funds for the Government bureaus under the Institution has vitally affected the work of those bureaus. The scientific series normally published by the National Museum and by the Bureau of American Ethnology have again been virtually suspended. During the emergency period of the depression, when ordinary governmental expenditures were greatly reduced, the brunt of the cut in Smithsonian appropriations was borne by the printing fund, as only there could a saving be made without throwing employees out of work. For 3 years the printing appropriation has been reduced to a point where it is possible only to do routine printing of blank forms and reports and a few very small pamphlets, with the result that there is now on hand an accumulation of valuable manuscripts, many of them representing the results of years of research by the Institution's specialists. This basic information in biology, geology, and anthropology should without further delay be made available to students and research workers, and it is the hope of the Institution that, now the peak of the depression is past, adequate funds will again be made available so that a normal flow of scientific publications may again issue from this Institution, whose very purpose, as incorporated by act of Congress, is "the increase and diffusion of knowledge among men."

The publications issued during the year, paid for mostly from the private funds of the Institution, totaled 64; 54 of these were published by the Institution proper, 8 by the National Museum, 1 by the Bureau of American Ethnology, and 1 by the Freer Gallery of Art. The number of publications distributed was 124,186.

LIBRARY

The accessions to the Smithsonian library during the year numbered 6,105 volumes and 6,578 pamphlets and charts, bringing the total number of items in the library to 848,517. Most of the additions were exchanges for Smithsonian publications, but there were also the usual large number of gifts from organizations and individuals. In addition to the routine work of the library, the staff completed several important projects begun last year, with the assistance of F. E. R. A. workers assigned to the library; these projects included sorting and arranging foreign scientific and technical duplicates in the west stacks of the Smithsonian building, and sorting and reassigning the contents of the sectional libraries of administration and engineering.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

Sir: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1935:

Appropriations for the maintenance of the National Museum for the year totaled $716,071, which was $61,200 more than for 1934.

COLLECTIONS

Material added to the collections during the year came in 1,794 separate accessions, mostly as gifts from outside individuals and organizations, and was varied and representative in character. It totaled 296,468 specimens, divided as follows: Anthropology, 3,758; biology, 258,692; geology, 28,528; arts and industries, 3,808; history, 1,682. Gifts to schools and other educational institutions numbered 4,039 specimens. Exchanges of duplicate material with other institutions and individuals totaled 17,194 specimens, and 17,783 specimens were lent to workers outside of Washington.

Following is a summary of the more important accessions received in the various departments:

Anthropology.—American ethnological material received from various sources represented the Point Barrow Eskimos, the Haida Indians of British Columbia and Alaska, the Navaho, the Tarahumare Indians of Mexico, the Delaware, Osage, Plains, Pueblo, and Yakima Indians of North America, and the San Blas Indians of Panama. From Matto Grosso, Brazil, came a number of weapons of the fierce Parintintin Indians, and from the head-hunting Jivaro of Ecuador a collection of textiles and adornments received through the Bureau of American Ethnology. Specimens came also from Africa, Oceania, and Malaysia. As in former years, ethnological material presented by Dr. Hugh M. Smith, fisheries adviser to the Royal Siamese Government, was extensive.

Among the noteworthy archeological material received was a plaster cast, presented by the Carnegie Institution of Washington, of the elaborately carved surface of a Maya altar at Quirigua, Guatemala, regarded as one of the finest examples of aboriginal

sculpture recovered from the Maya area. By transfer from the Bureau of American Ethnology came over 300 specimens collected by Dr. W. D. Strong from the Bay Islands and from the mainland of Spanish Honduras. Also may be mentioned 214 flint objects from a Paleolithic deposit in Mugharet et-Tabun (Cave of the Oven), near Mount Carmel, Palestine, deposited by the Archeological Society of Washington; 1,188 stone artifacts, basketry fragments, and other material collected by Frank M. Setzler from 2 caves in Val Verde County, Tex.; 3 terra-cotta cones from Ur of the Chaldees, Iraq, bearing inscriptions that date them about 2075 B. C., given by the Bruce Hughes fund; 52 stone implements from South Africa, donated by W. C. Abbott, of Cape Town; and earthenware vessels from Panama, ivory and bone harpoon heads from St. Lawrence Island, Alaska, and Paleolithic implements from the Thames Valley, England.

Skeletal material received came from Florida, California, and North Carolina, and from Kodiak Island, Alaska, collected by Dr. Aleš Hrdlička. Skeletons collected by Frank M. Setzler, though few in number, were important because of the new type and area represented.

Biology.—A special feature of this year's biological accretions was the large number of genera and species new to the collections. Much invaluable type material also was received. Many rare species of mammals and birds from Siam and China came from Dr. Hugh M. Smith and Dr. D. C. Graham, respectively, who contributed from these countries also considerable collections of reptiles and amphibians, fishes, insects, mollusks, marine invertebrates, and plants. Among the forms now represented for the first time were the Saiga antelope from the Kalmuk Steppes of South Russia (of which the Museum formerly had only a skeleton), a sloth (*Scaeopus*) and a monkey (*Brachyteles*) from South America, a porpoise taken on the third Hancock Galapagos expedition, 15 genera of birds, and a number of species of West Indian beetles. Other noteworthy accessions include: A large collection of Brazilian reptiles, amphibians, fishes, insects, and mollusks made by Dr. Doris Cochran; over 3,000 fishes comprising the private collection of Dr. G. S. Myers; 2,400 Florida fishes collected by C. R. Aschmeier; a collection of South American Homoptera made by the late Dr. F. W. Goding; a collection of Oriental insects made by T. R. Gardner; the J. E. Guthrie collection of Collembola; 3,000 New England insects, mostly Homoptera, from P. W. Oman; a valuable series of invertebrates collected under the auspices of the late C. C. Nutting, of the University of Iowa; crustaceans and other forms collected by Dr. W. L. Schmitt on the third Hancock expedition to the Galapagos Islands; about

30,000 mollusks, chiefly European, from Dr. H. R. K. Agersborg; and nearly 50,000 specimens of plants from many sources, representing a wide variety of localities.

Geology.—To the Canfield collection were added 174 mineral specimens, including a rich mass of North Carolina uraninite showing crystals and weighing over 5 pounds, obtained through the interest of Dr. H. P. Barret. Through the income of the Roebling fund 393 mineral specimens were added, of special interest being a collection of minerals from pegmatitic pockets in the granite area of Striegau, Germany, and the material resulting from Dr. W. F. Foshag's field work in Mexico under the auspices of the fund. Many of the Museum's friends contributed valuable mineral specimens, many of them from Mexico. Species of minerals new to the Museum include ahlfeldite, blockite, kolbeckine, and selenolite from Bolivia; aglaurite from Czechoslovakia; igalikite, metejarlite, and naujakasite from Greenland; johannsenite from Mexico; repossite from Italy; and sahlinite from Sweden. Dr. Eugene Poitevin presented a specimen of his new mineral ashtonite.

The increase in the meteorite collection was especially notable, 25 new falls being added, bringing to 592 the total number of distinct meteoric falls now represented.

About 500 rock specimens were added to the Henry S. Washington petrographic series. Accession of ores was of increased importance, several mining companies as well as individuals donating valuable samples. From the United States Geological Survey a collection of described material was received illustrating the petrology of the Louisiana and Texas cap-rocks.

The outstanding gift of the year in invertebrate paleontology was the Hurlburt collection of Lower Paleozoic fossils, especially rich in rare New York Ordovician trilobites, crinoids, cystids, and mollusks. This collection was presented by Edward N. Hurlburt, of Rochester, N. Y., as a memorial to his father, who assembled it in the early days of American paleontology. Nine gifts furnished fossils from countries beyond North America, which are especially valuable for comparative purposes. About 30,000 Devonian and other Paleozoic fossils were collected for the Museum by Dr. G. A. Cooper in Michigan, Ontario, and New York, and (with R. D. Mesler) about 10,000 fossils in Virginia, Tennessee, and Arkansas.

Materials resulting from the field expedition to Idaho under Dr. C. L. Gazin are of first importance in vertebrate paleontology. Fossil remains of the extinct horse *Plesippus shoshonensis* formed the bulk of the collections. An excellent skeleton of the sauropod dinosaur *Camarasaurus* was obtained through exchange with the Carnegie Museum of Pittsburgh.

Arts and industries.—The outstanding accession in aeronautics was the motorless sailplane *Falcon*, built in 1934 for the late Warren Eaton, which well illustrates modern progress in aerodynamic efficiency. It was presented by Mrs. Genevieve J. Eaton. The Maybach Motor Co. presented a Maybach engine, type VI–2, like that used in the *Graf Zeppelin* and other recent airships. Other aeronautic material received included the magnetic compass used by Admiral Byrd in his 1926 North Pole flight, 13 excellent scale models of aircraft, and a series of aluminum alloy fittings and airship girders.

In mechanical technology, models of watercraft figured in the accessions, the most important being the original models of the schooner *James S. Steele* and the knockabout *Helen B. Thomas*, designed by Capt. Thomas F. McManus.

The automobile collection was enhanced by the gift of William K. Vanderbilt of the cup presented to the winner of the first Vanderbilt Cup Race 30 years ago. One railroad accession was received—a model of the locomotive *DeWitt Clinton* and train, the first locomotive to run in the State of New York.

One hundred and eight specimens of new textile fabrics, illustrating new weaves and combinations; 31 dioramas showing the history of medicine-making; and a complete Mergenthaler linotype (no. 9) were among other outstanding accessions.

History.—Over 1,600 articles of historical and antiquarian import were received, many falling within the military and naval categories. The numismatic collection was increased by 136 coins and the philatelic series by 1,314 stamps.

EXPLORATIONS AND FIELD WORK

Field work carried on during the year was financed mainly through grants from the invested funds of the Smithsonian Institution, with some additional assistance from such outside sources as the P. W. A. and interested friends.

Anthropology.—In December, Herbert W. Krieger, curator of ethnology, brought to a close the archeological work commenced last year in the Columbia River Valley. Search for new light on early Virginia tribal life was made by Mr. Krieger and H. B. Collins, Jr. in field studies made at Indian village sites along the lower Potomac River and elsewhere in the State.

Frank M. Setzler, assistant curator of archeology, late in 1934, accompanied Dr. John R. Swanton in a trip by automobile through Virginia, North Carolina, South Carolina, Georgia, and Florida, to seek information concerning the route traveled by Hernando De Soto in 1539 and 1540 and to examine vestiges of certain Indian villages mentioned by the chroniclers of the De Soto expedition.

Dr. Aleš Hrdlička, curator of physical anthropology, with a group of five students, continued his archeological work on Kodiak Island, Alaska, which has been in progress intermittently since 1932.

Biology.—Dr. Waldo L. Schmitt, curator of marine invertebrates, by invitation participated again in Capt. G. Allan Hancock's expedition to the Galapagos Islands on the yacht *Velero III*, and brought back several thousand natural-history specimens.

Dr. Doris M. Cochran, assistant curator of reptiles and amphibians, under a grant from the Smithsonian Institution, was detailed to Brazil to study Brazilian amphibians. She returned early in June with many thousand specimens, including not only amphibians and reptiles but also representing several other branches of zoology.

Gerrit S. Miller, Jr., curator of mammals, spent several weeks studying the fauna of the outlying keys of southern Florida and made extensive collections there of mammals, reptiles, and other forms.

Dr. Hugh M. Smith, honorary associate curator of zoology, who for many years has represented the Museum in explorations in Siam, returned to Washington and brought with him large collections that added greatly to the Museum's Siamese material. Dr. D. C. Graham, honorary collaborator in biology, from his headquarters at Chengtu, China, continued to send valued specimens resulting from his excursions in the Chinese province of Szechwan.

Jason R. Swallen, Department of Agriculture botanist, brought to a close a successful period of exploration for grasses in Brazil and obtained about 8,000 specimens. Another piece of field work concluded was that of Dr. Alan Mozley, working under the Walter Rathbone Bacon traveling scholarship in a study of Siberian mollusks. Also may be mentioned local work by members of the Museum staff on a study of the biota of Maryland and Virginia: Dr. G. S. Myers and E. D. Reid studied and collected fresh-water fishes from this area; Dr. Paul Bartsch made extensive collections of mollusks, amphibians, and birds with reference to the District of Columbia fauna; and Austin H. Clark studied Virginia butterflies, visiting 54 counties of the State.

Prof. C. E. Burt, of Southwestern College, under a grant from the Smithsonian, worked in Mississippi, Louisiana, and Texas collecting a series of turtles for the Museum.

Geology.—C. W. Gilmore, curator of vertebrate paleontology, near the close of the year left for Montana to take charge of an expedition into the Judith River (Upper Cretaceous) of that State, where a search was to be made for dinosaur material.

The expedition under the direction of Dr. C. L. Gazin, assistant curator of vertebrate paleontology, at the fossil quarries near Hagerman, Idaho, was gratifyingly successful, the material acquired nearly

equaling the previous combined collections from the same locality. Fossil remains of the horse *Plesippus* formed the bulk of the material.

Dr. W. F. Foshag, curator of mineralogy, spent 4 months in Mexico collecting minerals under the auspices of the Roebling fund, visiting important mining districts in the Sierra Madres of western Chihuahua and vicinity and in southern Mexico.

E. P. Henderson, assistant curator of mineralogy, investigated reports of meteorites and collected minerals in Arkansas, Kansas, and Virginia.

Dr. G. A. Cooper, assistant curator of stratigraphic paleontology, with a group of Geological Survey geologists, studied the region near Phillipsburg, Quebec, and collected many fossils. He also visited the lower peninsula of Michigan, to study the Devonian strata near Alpena, as well as southwestern Ontario, northwestern Ohio, and western New York. Also, with R. D. Mesler, of the Geological Survey, he collected fossils at Batesville, Ark.

MISCELLANEOUS

Visitors.—Visitors during the year to the various Museum buildings totaled 1,841,306, an increase of 377,931 over the previous year. The annual attendance in the several buildings was recorded as follows: Smithsonian Building, 307,240; Arts and Industries Building, 798,535; Natural History Building, 606,145; Aircraft Building, 129,386. During April 1935 there were 307,739 visitors, the largest number ever recorded for a single month.

Publications.—On account of the greatly curtailed allotments for printing, the publication output of the Museum was small. Only 8 papers were issued during the year, including the annual report for 1934 and 7 Proceedings papers. These are listed elsewhere in this report. Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 26,592 copies.

Work was continued, under the supervision of the Museum editor, on the preparation of the index to Museum publications started last year.

Special exhibits.—Seventeen special exhibits were held during the year, under the auspices of various educational, scientific, and Government agencies, including, among others, the American Forestry Association, the Potomac Rose Society, the District of Columbia Dental Society, the American Society of Photogrammetry, the Public Works Administration, and the Commission of Fine Arts.

Changes in organization and staff.—Dr. Edward A. Chapin, of the United States Bureau of Entomology and Plant Quarantine,

was appointed on July 1, 1934, to succeed the late Dr. John M. Aldrich as curator of the division of insects. In the division of mollusks, Dr. Joseph P. E. Morrison was appointed senior scientific aid on August 2. A realignment of work in the division of graphic arts resulted in the permanent appointment on May 20, 1935, of C. Allen Sherwin as scientific aid. Miss Mary E. Dillingham was appointed junior scientific aid in the division of textiles on October 15, 1934.

Three Museum employees were transferred from the active to the retired list, as follows: Philip N. Wisner, assistant clerk, on November 30, 1934, through disability; Mrs. Amelia Turner, under photographer, on June 30, 1935, through section 8 (a) of the Economy Act; and Mrs. Rachel Turner, charwoman, on August 31, 1934, through age.

Necrology.—The Museum lost through death 2 of its honorary staff members and 7 of its active workers, as follows: Dr. Albert Mann, honorary custodian of diatoms since January 8, 1913, who died on February 1, 1935; Dr. David White, honorary associate curator of paleobotany since May 23, 1905, who died February 7, 1935; Peter Hanson, machinist, who died on March 6, 1935; Frank W. Mullen, electrician's helper, on February 18, 1935; Michael Colohan, John J. Gallagher, and Harrison M. Kinnison, guards, on July 11, 1934, December 9, 1934, and June 4, 1935, respectively; Mrs. Marie Ellis, charwoman, on March 29, 1935; and Mrs. Lula Bryant, attendant, on April 16, 1935.

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit the following report on the activities of the National Gallery of Art for the fiscal year ended June 30, 1935:

In the past 12 months several events have taken place which may have a bearing on the future of the National Gallery of Art, and so it will be of interest to record them here.

The press has reported that the Mellon Foundation may locate in Washington a gallery of art to house the Mellon collection of paintings as well as other masterpieces. The details of the foundation and its relation to the National Gallery of Art have not been definitely decided.

Senator David I. Walsh, of Massachusetts, introduced into the Senate a bill which may lead to the formation of a National Portrait Gallery under the direction of the Smithsonian Institution.

Representative William I. Sirovich, of New York, Chairman of the Committee on Patents, held extensive hearings on House Joint Resolution No. 220, which relates to the proposed formation of a new Government department to be called the "Department of Science, Art, and Literature."

The Government has placed artists in the Civilian Conservation Corps camps to record their activities. It has also awarded many contracts for the decoration of Government buildings throughout the United States.

These events show that there is a widespread interest in art in our country and raise the hope that the Government will sooner or later provide a building where the works of art in its possession can be properly shown. Collectors as a rule want their treasures in some permanent museum, and would be attracted by the high standing of a national gallery comparable to those of the European countries. Seldom are collectors able to do as did Mr. Freer—furnish the material, the building, and also the money for its upkeep, so that the Freer Gallery is an almost independent unit under the direction of the Smithsonian Institution. Many collectors, when they shall see a proper building for the National Gallery of Art, and the material in it properly cared for, will feel that they have found the most suitable place to give their collections. But without a building, with no room to expand, our collections must stand still.

APPROPRIATIONS

For the administration of the National Gallery of Art by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $32,768 was appropriated.

THE NATIONAL GALLERY OF ART COMMISSION

The fourteenth annual meeting of the National Gallery of Art Commission was held at the Smithsonian Institution on December 11, 1934. The members present were: Dr. Charles G. Abbot, secretary of the Smithsonian Institution, who is ex-officio member and also the secretary of the Commission; Frank Jewett Mather, Jr., vice chairman; Herbert Adams; Gifford Beal; Charles L. Borie, Jr.; James E. Fraser; Frederick P. Keppel; John E. Lodge; George B. McClellan; Charles Moore; Edmund C. Tarbell; and Mahonri M. Young. Ruel P. Tolman, curator of the division of graphic arts in the United States National Museum and acting director of the National Gallery of Art, was also present.

The Commission recommended to the Board of Regents the re-election for the succeeding term of 4 years of the following members: Herbert Adams, Gifford Beal, and Charles Moore.

The following officers were re-elected for the ensuing year: Joseph H. Gest, chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary; as well as the members of the executive committee: Charles Moore, Herbert Adams, and George B. McClellan. Joseph H. Gest, as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex-officio members.

The following resolution was adopted as an expression of the Commission's general policy in connection with gifts or bequests offered with certain undesirable restrictions:

> *Resolved*, That it is the recommendation of the National Gallery of Art Commission that the Smithsonian Institution do not in general accept for the National Gallery of Art gifts or bequests of miscellaneous collections of objects of art when a condition is attached thereto that the objects must be exhibited in perpetuity.

[Joseph H. Gest, chairman of the National Gallery of Art Commission, died on June 26, 1935, at Cincinnati, Ohio.]

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution are as follows:

Two portraits by George Peter Alexander Healy (1808–1894), of Gen. William Tecumseh Sherman, 1866, Regent of the Smithsonian

Institution in 1871 and 1878; and of Mrs. William Tecumseh Sherman (Ellen Boyle Ewing Sherman), 1868. Presented by their son, P. Tecumseh Sherman, of New York, N. Y. (Accepted for the National Portrait Gallery.)

Two portraits by Jean Joseph Benjamin-Constant (1845–1902), of the Honorable John B. Henderson, Regent of the Institution from 1892–1911, and of Mrs. Henderson (Mary Newton Foote Henderson). Gift of the heirs of Mrs. Mary F. Henderson through Dr. Charles Moore.

Three paintings by Georg Ernst Fischer (1815–1874): "American Country Life, about 1860", "Cupids", "Gratitude", and a plaque of Francis Davis Millet (1846–1912) at the age of 32, dated Paris, March 1879, by Augustus Saint Gaudens. Gift of Ernst G. Fischer, of Washington, D. C.

Portrait of His Majesty King George V of Great Britain, by Frank O. Salisbury. Presented to President Franklin Delano Roosevelt for the American Nation by the artist in commemoration of the valiant service rendered by the Republic of the United States of America and the British Empire in behalf of justice and peace, May 6, 1935. Jubilee Year. Accepted by President Roosevelt at special presentation exercises, July 11, 1935, at the White House.

A peachblow vase, product of the K'Ang-hsi period, presented to the Government of the United States for the National Museum by the Imperial Chinese Government in 1908, was transferred by the Museum to the National Gallery of Art.

THE CATHERINE WALDEN MYER FUND

Two Early American miniatures were acquired from the fund established through the bequest of the late Catherine Walden Myer—a fund for the purchase of first-class works of art for the use and benefit of the National Gallery of Art, as follows:

"Portrait of Jane Stone", by Benjamin Trott (about 1770–1839); from Miss Marion Lane, of Washington, D. C.

"Portrait of Judge Thomas Waties" (born in Georgetown, S. C., in 1760), by Charles Fraser (1782–1860); from Miss Marie R. Waties, of Washington, D. C. (A loan from Miss Waties during the last fiscal year.)

LOANS ACCEPTED BY THE GALLERY

Portraits by Henry Inman (1801–1846) of Col. Robert Charles Wetmore and of his wife, Adeline Geer Wetmore, bequeathed to the United States National Museum by Florence Adele Wetmore,

late of New London, Conn. Lent by the United States National Museum.

A pair of Meissen vases, 23½ inches high. Lent by Mr. and Mrs. J. D. Patten, of Du Bois, Pa.

Three small bronzes by A. L. Barye (1796–1875), as follows: "Panther Surprising Civet Cat", "Stork on Tortoise", and "Seated Hare." Lent by Leonard C. Gunnell, of the Smithsonian Institution.

Two pastel portraits in profile by James Sharples (about 1751–1811), of Gen. George Washington and of Martha Washington. These were the property of Washington and hung originally in Mount Vernon. Lent by Mrs. Robert E. Lee, of Washington, D. C., Dr. George Bolling Lee, of New York, N. Y., Mrs. Hanson E. Ely, Jr., of Washington, D. C., and Mrs. William Hunter de Butts, of Upperville, Va.

Bronze group by Herbert Haseltine, 1920, entitled "Field Artillery." Lent by the Honorable Robert Woods Bliss, Washington, D. C.

An oil painting (one side of a diptych) by Gabrielle DeV. Clements, entitled "An Angel." Lent by the artist, and withdrawn by her before the close of the year.

A collection of 8 miniatures, 2 silver snuff boxes, a watch, a mourning ring, and a portrait ring. "The Theodosia Lawrence Barnard Talcott Collection", lent by Miss Lucia B. Hollerith, of Washington, D. C.

Six miniatures of the Shippen family as follows: Rebecca Lloyd (1785 or 1787), attributed to Richard Cosway (1740–1821); Jane Gray Wall, by John Francis Burrell, London (about 1800); Ann Hume Shippen, attributed to Benjamin Trott (about 1770–1839); Mrs. Thomas Lee Shippen, signed Bridport; Thomas Lee Shippen, by James Peale—signed I. P. and dated 1793; William Shippen, by James Peale—signed I. P. and dated 1794. Lent by Dr. Lloyd P. Shippen, of Washington, D. C.

GALLERY LOANS RETURNED

The "Portrait of Mrs. Price", by William Hogarth, lent to the Art Institute of Chicago for "A Century of Progress Loan Exhibition of Fine Arts", from June 1 to October 31, 1934, was returned to the gallery on November 9, 1934.

Sixteen bound volumes: "Random Records of a Lifetime Devoted to Science and Art, 1846–1932", by W. H. Holmes, consisting of letters, manuscripts, photographs, drawings, and sketches, compiled and presented to the National Gallery library by Dr. Holmes, but retained by him for additions when he retired from Government service, were returned by his family during the year.

LOANS BY THE GALLERY TO OTHER INSTITUTIONS

Five paintings by contemporary American artists, from the William T. Evans collection, were lent to the M. H. de Young Memorial Museum of San Francisco, Calif., for an important exhibition of American paintings from the eighteenth century to the present day, held from June 7 to July 7, 1935, as follows: "Moonrise", by Ralph Albert Blakelock; "September Afternoon", by George Inness; "High Cliff, Coast of Maine", by Winslow Homer; "Moonlight", by Albert Pinkham Ryder; and "Caresse Enfantine", by Mary Cassatt. (These paintings have been returned to the National Gallery.)

Five portraits were lent to the Public Library of the District of Columbia for exhibition in the central library from June 18, 1935, for 6 months, as follows: "John Tyler", by G. P. A. Healy; "A Lady", by Gilbert Stuart; "Col. Robert Charles Wetmore", by Henry Inman; "Andrew Jackson", by Rembrandt Peale; and "Commodore Stephen Decatur", by Gilbert Stuart.

WITHDRAWALS BY OWNERS

Seven pieces of Early English, Irish, and American silver, received as a loan on June 23, 1934, from Mrs. George Morris, Washington, D. C., were withdrawn by the owner on October 10, 1934.

The portrait of Thomas Amory, by Gilbert Stuart, formerly the property of Mrs. O. H. Ernst, was delivered at Mrs. Ernst's direction on November 6, 1934, to her daughter, Mrs. William Grinnell, of New York, N. Y., the present owner.

SPECIAL EXHIBITIONS

Seven exhibitions were held in the foyer of the Natural History Building of the United States National Museum, as follows:

July 6 to August 31, 1934.—Water colors and black-and-white drawings (114) by Clayton Knight, made during a 20,000-mile journey by air over South America, the West Indies, and Central America. Cards were issued by the Gallery, and a seven-page catalog furnished by the exhibitor.

January 10 to 31, 1935.—Water-color studies (30) of Mexico and Massachusetts, made during the summers of 1934 and 1933, by Alexander Trowbridge. Cards were issued by the Gallery, and a folder-catalog supplied by the exhibitor.

January 10 to 31, 1935.—Oil paintings (56) by Emil Jacques, instructor in the art department of the University of Notre Dame, Indiana. Cards were issued by the Gallery and folder-catalogs supplied by the exhibitor.

February 14 to March 15, 1935.—Forty lithographs of Boulder Dam by William Woollett, architect. No catalogs were provided, each specimen being plainly labeled.

April 4 to 30, 1935.—Oil paintings and water colors by the Misses Elena and Bertha de Hellebranth, exhibited under the patronage of His Excellency the Minister of Hungary, John Pelenyi. Cards were issued by the Gallery and folder-catalogs furnished by the exhibitors.

May 2 to 31, 1935.—Exhibition of pastel studies (65) of Egyptian peasant types, by Howard Fremont Stratton, under the patronage of His Excellency Ibrahim Ratib Bey, E. E. and M. P. of His Majesty the King of Egypt, and others. Cards were issued by the Gallery, but no catalogs were furnished, each specimen being plainly labeled.

June 4 to 20, 1935.—Oil paintings, water colors, and drawings by artists enrolled in the Civilian Conservation Corps camps were shown under the direction of the Director of Emergency Conservation Work and members of his Advisory Council.

THE NATIONAL GALLERY REFERENCE LIBRARY

The library now comprises over 4,500 publications, accessions for the year amounting to 568, acquired by gift, exchange, and purchase. Books totaling 773, in addition to 1,162 parts of publications, were transferred from the section of administration of the United States National Museum to form part of the National Gallery Library when cataloged.

SPECIAL ACTIVITIES

The acting director visited various museums throughout the country for the purpose of studying their collections as follows:

A visit was made (July 27 to Aug. 24, 1934) to Philadelphia, Princeton, Newark, and to practically all the public art collections in New England, from New Haven, Conn., to Brunswick, Maine, to Burlington, Vt., and down the Connecticut Valley back to New Haven.

A special exhibition of 50 paintings by Frans Hals was visited at the Detroit Institute of Art, Detroit, Mich., in February 1935.

The opportunity was taken to visit and study the exhibition of miniatures, the product of the leading painters of the eighteenth and nineteenth centuries, shown at the Gibbes Memorial Art Gallery, Charleston, S. C., February and March 1935.

Glass, and the making of glass, at the Corning Glass Works, Corning, N. Y., were studied in June 1935, in connection with the work of John Northwood, of which the National Gallery has a fine example in the John Gellatly Collection.

PUBLICATIONS

TOLMAN, R. P. Report on the National Gallery of Art for the year ending June 30, 1934. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1934, pp. 23–28.

——— The technique of Charles Fraser, miniaturist. Part I. Antiques, vol. 27, no. 1, pp. 19–21, 11 ills., Jan. 1935. Part II. Antiques, vol. 27, no. 2, pp. 60–62, 12 ills., Feb. 1935.

LODGE, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1934. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1934, pp. 29–32.

CATALOG: Water colors and black and white drawings by Clayton Knight. Made during a 20,000-mile journey by air over South America, the West Indies, and Central America. July 6–Aug. 31, 1934. National Gallery of Art, Smithsonian Institution. Washington, D. C., 7 pp. Privately printed.

CATALOG: Smithsonian Institution, National Gallery of Art, Washington. Exhibition of oil paintings by Emil Jacques. From Thursday, January 10 until Thursday, January 31, inclusive, 1935. 4-page leaflet, privately printed.

CATALOG: Water Color Studies of Mexico and Massachusetts made during the summers of 1934 and 1933 by Alexander Trowbridge. January 10 to January 31, inclusive, 1935. National Gallery of Art, Smithsonian Institution, Washington, D. C. Leaflet of 3 pp. Privately printed.

CATALOG: Exhibition of Paintings by Bertha de Hellebranth and Elena de Hellebranth. Sponsored by His Excellency John Pelényi, the Minister of Hungary, at the United States National Museum, National Gallery of Art, Washington, D. C., April 4–30, 1935. 3-page leaflet, privately printed.

Respectfully submitted.

R. P. TOLMAN, *Acting Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the fifteenth annual report on the Freer Gallery of Art, for the year ended June 30, 1935:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

35.12. Chinese, Chou period. A ceremonial covered vessel of the type *chia*, with four legs and three handles. The surface is decorated with designs in delicate low relief; a bird finial on the cover. Green patina. Inscription inside. Height, 0.407 over all. (Illustrated.)

35.6. Chinese, T'ang period. A miniature mirror with scalloped edge, its back inlaid with sheet gold having concentric designs of running animals, 6-petaled rosettes, and a scroll pattern executed, respectively, in high, medium, and low relief. Diameter, 0.055.

35.13. Chinese, Han or earlier. A mirror, with a glossy mottled black and gray patina and malachite encrustations. Decoration: A landscape with groups of people and animals in a sharply cut low relief repeated four times; ornamented knob. Diameter, 0.184. (Illustrated.)

35.14. Chinese, Han or earlier. A mirror (one repair) with a glossy black patina and patches of azurite. Decoration: A scroll pattern on a bed of fret work, in sharply cut relief. Diameter, 0.233. (Illustrated.)

CERAMICS

34.22. Chinese, T'ang dynasty. Mortuary pottery: A long-necked flask; the belly decorated with an incised design of lotus flowers and foliage, the whole glazed with green, yellow, and cream color; the surface now largely iridescent. 0.252 by 0.136.

35.3. Chinese, Sung dynasty. *Lung-ch'üan yao:* A tea bowl, covered with a lustrous celadon glaze. 0.052 by 0.138.

35.4. Chinese, Sung dynasty. *Kuan yao:* A round covered box with a celadon glaze of brilliant luster. Decoration: A floral design in relief under the glaze. 0.028 by 0.093.

35.5. Chinese, Ming dynasty. A pottery bowl glazed in brilliant blue; decorated with incised line drawing under the glaze. Mark, Chêng Tê (1506–1521). 0.056 by 0.117.

GLASS

35.15–35.16. Syrian (Christian), late fourth century. A pair of altar cruets, each one 6-sided with trefoil lip and hollow handle. Dark brown, translucent blown glass with areas of partial disintegration appearing in cream-colored flecking and brilliant iridescence. Decoration: Early Christian symbols in counter-sunk relief. 0.162 by 0.094; 0.157 by 0.101.

JADE

35.7. Chinese, Chou period. A badge of rank of the type *kuei*. Color: Deep cream and soft light brown, with a few streaks of darker brown. 0.175 by 0.040 by 0.012.

MANUSCRIPTS

34.24–34.28. Arabic (North Africa), twelfth century. Bound volume of a portion of the *Qua'ān;* parchment. Written in *maghribī* script in dark brown ink; orthographical signs in red, blue, and yellow; illuminated lectionary marks. Four pages illuminated in gold (34.25–34.28). 0.165 by 0.115.

35.18. Persian, sixteenth century (A. D. 1546). Bound book; *Gūy u-Chawgān* (The Ball and the Polo-mallet) by Ārifī of Herāt; calligrapher, Shāh Maḥmūd Nīshāpūrī. Text in *nasta'līq* script. Two illustrations (see below under Paintings: 35.19, 35.20).

PAINTINGS

35.8. Chinese, Sung period. Women bathing and dressing children: An album picture. Painted in full color on a fan-shaped piece of silk; 10 seals on the painting. 0.227 by 0.244. (Illustrated.)

35.9. Chinese, Sung period. Two women with attendants: An album picture. Painted in full color on a fan-shaped piece of silk; 11 seals on the painting. 0.227 by 0.244. (Illustrated.)

35.10. Chinese, twelfth–thirteenth century. Sung period. By Yen Tz'ŭ-yü. Landscape: An album picture. Painted in ink and tint on silk. Signature and 10 seals on the painting. 0.253 by 0.258. (Illustrated.)

35.11. Chinese, tenth–eleventh century. Sung period. Tun-huang type. Kṣitigarbha (Ti-tsang) and one of the Ten Kings of Hell. In the lower register, Vajrasattva and a donor. Painted in full color on silk. 1.064 by 0.582. (Illustrated.)

35.17. Chinese, Sung period. By Mi Yu-jên (1086–1165). "Wooded hills and autumn mists." Painted in ink monochrome. Title, signature, and 14 seals on the painting. Paper *makimono*, 0.23 by 2.319.

35.2. Indian, A. D. 1600, or earlier. Rājput, Rājasthānī. Krišnā and Rādhā. Painted on paper in solid colors and slight gold. 0.205 by 0.157. (Illustrated.)

35.19–35.20. Persian, sixteenth century (A. D. 1546). Safawīd period. Two illustrations from the manuscript book of *Gūy u-Chawgān* (35.18; see above). Painted in colors and gold on paper:

(a) A polo game, 0.194 by 0.123. (Illustrated.)

(b) Scene in a polo field, 0.195 by 0.123. (Illustrated.)

SILVER

34.23. Persian, fourth century. Sāsānian period. A memorial plate, decorated with the figure of Sapor II (A. D. 309–380) on horseback hunting wild boar, executed in applied hollow relief, gilded. Diameter, 0.24. (Illustrated.)

WOOD-CARVING

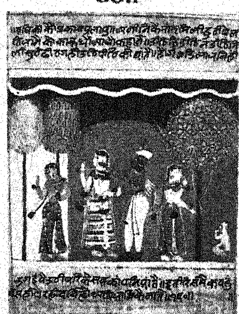
35.1. Arabic (Persia), late eleventh century. Seldjuk period. One leaf of a double door (repaired; four patches). Decoration consisting of inscriptions in ornamented *kūfic* script, cut in counter-sunk relief to a depth of 0.019. 1.440 by 0.483 by 0.05. (Illustrated.)

34.23

35.19

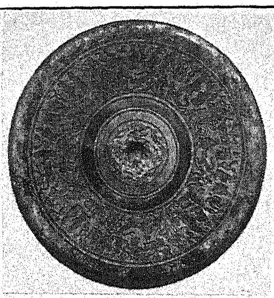
35.1

35.20

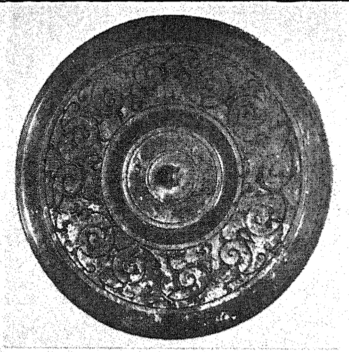


35.2

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART

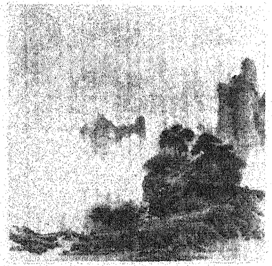


35.13



35.14

35.11



35.10

35.8

35.12

35.9

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

Curatorial work within the collection has been devoted to the study of Chinese, Japanese, Armenian, Arabic, and Persian objects, and of the texts and seals associated with them, including those newly acquired; also to the examination of objects submitted to the curator by other institutions or by private owners for an opinion as to their identity, their meaning, or their historic or esthetic value. A total of 1,268 objects and 153 photographs of objects were examined in this way and written or oral reports were made upon them. Also, 14 texts were submitted for translation.

Changes in exhibition have involved a total of 190 subjects, as follows:

Book-bindings	6	Paintings, Japanese	18
Bronzes, Chinese	11	Paintings, Persian	9
Glass, Syrian	7	Pottery, Chinese	19
Manuscripts	9	Pottery, Persian	15
Paintings, American	78	Silver, Persian	1
Paintings, Chinese	6	Stone sculpture, Chinese	4
Paintings, Indian	6	Wood-carving, Persian	1

The special exhibition of Whistler's work installed on May 14, 1934, in honor of the Whistler Centenary, was taken down on December 26.

ATTENDANCE

The Gallery has been open every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 130,323. The total attendance for week days, exclusive of Mondays, was 86,754; for Sundays, 43,569. The average Sunday attendance was 837, the average week-day attendance 335, a ratio of 2½ to 1. As always, the highest monthly attendance was reached in April (26,323) and August (13,296). The lowest monthly attendance was in December (5,576).

The total attendance of visitors on Mondays, by the south entrance, was 23, making a grand total attendance of 130,346.

There were 1,734 visitors to the offices during the year. The purposes of their visits were as follows:

For general information		315
To see objects in storage		304
Far Eastern paintings	106	
Near Eastern paintings	19	
American paintings	63	
Whistler etchings	6	
Oriental pottery, bronzes, sculptures, jades	110	
To examine building and installation		36
To read in the library		260
To see Biblical manuscripts		44

To make tracings and sketches from library books	29
To obtain permission to photograph or sketch	10
To examine or purchase photographs	371
To submit objects for examination	119
To see members of the staff	234

DOCENT SERVICE

Seventy-eight groups ranging from 1 to 40 persons (total 447) were given docent service in the exhibition galleries upon request (of these, 6 groups totaling 11 persons, on Mondays). Sixteen groups ranging from 11 to 18 persons (total 221) were given instruction in Chinese arts in the study rooms.

AUDITORIUM

The following groups have held meetings in the Auditorium:

October 27, 1934: Teachers of art in the Public Schools of the District of Columbia, and students. Attendance 200.

May 24, 1935: The technical section of the American Association of Museums. Attendance 15.

PERSONNEL

Mr. and Mrs. Carl W. Bishop returned to the Gallery on November 7, 1934.

Grace T. Whitney worked intermittently at the Gallery between October 10, 1934, and June 24, 1935, on translation of Arabic and Persian texts.

Grace Aasen Parler, librarian, was permanently transferred from the Smithsonian Library to the Freer Gallery Library on January 1, 1935.

Walter McCree, laborer, was permanently appointed to succeed John Pinkney, July 1, 1934.

Respectfully submitted.

J. E. Lodge, *Curator.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1935, conducted in accordance with the act of Congress of March 28, 1934. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $52,910.00.

SYSTEMATIC RESEARCHES

M. W. Stirling, Chief, left Washington on October 23, 1934, to investigate the location of finds of the eastern type of Folsom point in King and Queen and Halifax Counties, Va., and in Granville County, N. C. It was discovered that the points in question were all surface finds, the exact location of several being examined. Two interesting facts developed from this study: None of the Folsomlike points was found in connection with village site material, and all of them were recovered from hilltop fields or other elevations where erosion had removed the topsoil. Until finds are made in situ, and in association with other material, very little can be said as to the antiquity of the specimens beyond the fact that they appear to be earlier than the ceramic horizons in the same region.

On January 18, 1935, Mr. Stirling arrived at San Jose, Guatemala, from which point he visited archeological sites on the Pacific Coastal Plain. Proceeding to the highlands of Guatemala, he visited several Maya Quiche villages in the vicinity of Lake Atitlan and Chichicastenango. Subsequently he studied the old empire ruins of Quirigua on the Motagua River and Copan in Honduras. After returning to Guatemala from Honduras, Mr. Stirling proceeded to Yucatan, where he spent a week as a guest of the Carnegie Institution in viewing the sites of Uxmal and Chichen Itza. On February 12 he returned to Washington.

On June 18 Mr. Stirling left Washington for Macon, Ga., to examine the progress made by Dr. A. R. Kelly on the large-scale

mound excavations near that city. From Macon Mr. Stirling proceeded to Brunswick, Ga., to view some of the archeological sites on the Sea Islands and to consult with National Park Service officials regarding the establishment of archeological monuments in that area. From Brunswick he went to Manatee, Fla., to examine some interesting Calusa material discovered by Montague Tallant. Following this, a brief trip was made to Cape Sable and the Florida Keys to locate some of the southernmost examples of Calusa archeological sites. On the return trip to Washington, he spent 2 days at Tallahassee, Fla., in consultation with Vernon Lamme, Florida State Archeologist, and visited several interesting sites in the vicinity.

Dr. John R. Swanton, ethnologist, devoted a considerable part of the year to the amplification of his report on the Southeastern Indians, material being added from Spanish, French, and English sources.

In November and the first week of December, Dr. Swanton, accompanied by F. M. Setzler, assistant curator of archeology in the United States National Museum, visited Macon, Ga., as the guests of Dr. and Mrs. Charles C. Harrold, stopping on the way at various points in North Carolina to examine archeological collections and sites connected with the expedition of De Soto. They remained in Atlanta, at the invitation of Mr. and Mrs. Beverly M. Du Bose, long enough to view the famous Etowah mounds at Cartersville. Besides visiting several sites in the immediate neighborhood of Macon, they made a trip to Panama City, Fla., and with the helpful cooperation of Judge Ira A. Hutchinson of that place viewed many of the sites explored by Clarence B. Moore and obtained an excellent collection of potsherds from one of the large shell heaps. On the return trip to Washington productive attempts were made to identify sites visited by De Soto in both North and South Carolina. Lectures were delivered at Macon and also at Emory University, Atlanta, before those interested in the local archeology.

During the last week in December, Dr. Swanton took part in a conference on the prehistory of the lower Mississippi Valley at Baton Rouge, La., and on his way back spent some time visiting Indian sites along Alabama River with James Y. Brame, Jr., of Montgomery, Ala.

Shortly before the end of the year Dr. Swanton took up again his work on the Timucua linguistic material, which had been laid aside for some time. Timucua is no longer spoken, and, with the exception of two letters and some isolated words, all that is known regarding it is contained in five early seventeenth-century religious works published by the Franciscan friars Pareja and Movilla, with a grammar by the former.

At the beginning of the year Dr. Truman Michelson, ethnologist, was engaged in working out the phonetic shifts of Natick on the basis of the material contained in Trumbull's Dictionary. With very few exceptions these are now satisfactorily solved, and have been indexed on file cards. When a few remaining obscure points are elucidated it will be possible to present a complete paper for publication. During the year a number of technical papers were prepared for publication in certain professional periodicals. Among these is a series of papers solving certain difficulties in Algonquian sound-shifts and etymologies as well as showing that some sound-shifts took place in Proto-Algonquian times. An article on Winnebago social and political organization should also be noted. The data extracted from Caleb Atwater's writings, previously neglected, are important. A new technique of determining the gentes of some tribes at certain times is given. Since gentes often own personal names, it is clear that personal names occurring as the signers of treaties and in early documents can be utilized in determining the gentes. Of general ethnological interest will be Dr. Michelson's communication, shortly to be published in the American Anthropologist, on Miss Owen's Folk-Lore of the Musquakie Indians. Since the book deals with the Musquakie Indians, we have a right to suppose that the Indian words cited are Musquakie. However, Dr. Michelson shows that several are not even Algonquian but Siouan. Dr. Michelson has prepared and submitted for publication two papers: "Further Notes on Algonquian Kinship Terms" and "What Happened to Green Bear Who Was Blessed with a Sacred Pack."

Dr. John P. Harrington, ethnologist, continued during the year his researches on the Indians of California and other related western Indians, both in the field and in Washington. At the beginning of the year he was engaged in work in southern California with an aged Indian, reviewing with him the ethnology contained in Father Boscana's unique report on the culture of the southern California coast Indians, written in 1822, the manuscript of which Dr. Harrington recently discovered. The rehearing and annotating of this important manuscript was continued with other informants until well into the fall, resulting in the elucidating of practically every passage of the old text. On the completion of this work Dr. Harrington returned to Washington, D. C., to continue the annotation of the Boscana manuscript. Owing to the presence of Mission Indians in the city of Washington during all the latter part of the year, as delegates in connection with legislative work, Dr. Harrington availed himself of this opportunity to amplify the work. Legends and other materials from these Indians were reheard, discussed, and edited. This work was still in continuation on June 30.

Dr. Frank H. H. Roberts, Jr., archeologist, devoted considerable time during the year to a study of the problem of so-called Folsom man. Extensive correspondence was carried on with collectors throughout the country concerning their finds of Folsom points and many examples were sent to him for study, photographing, and measuring. As a result of this work much new information was obtained concerning variations in this peculiar type of projectile point and its distribution.

Dr. Roberts left Washington September 23, 1934, for Fort Collins, Colo., to investigate a site which had been reported to the Smithsonian Institution by Maj. Roy G. Coffin, professor of geology in Colorado State College. The site was discovered in 1924 by Judge C. C. Coffin and his son, A. L. Coffin, of Fort Collins. Among the specimens were points which later were identified as belonging to the Folsom type, the oldest thus far known in North America. Dr. Roberts spent 6 weeks exploring the site, with the permission of the owner of the land, William Lindenmeier, Jr., of Fort Collins. From an intact midden layer 14 feet below the present ground level, and a quarter of a mile distant from the place of the original finds by the Coffins, he procured a whole series of implements which definitely establish a complex for the Folsom horizon.

Dr. Roberts returned to Washington November 20, 1934, and during the winter months prepared a manuscript detailing the results of his work. This paper, entitled "A Folsom Complex: Preliminary Report on Investigations at the Lindenmeier Site in Northern Colorado", was published June 20, 1935, in the Smithsonian Miscellaneous Collections, vol. 94, no. 4, publ. no. 3333.

Dr. Roberts left Washington again for Fort Collins on May 26. A camp was established at the Lindenmeier site and excavations on a larger scale than those of the preceding autumn were begun. The digging yielded numerous specimens of stone implements and a considerable quantity of bison bones, indicating that they are from much larger animals than the modern bison. A number of stone implements were found in direct association with these bones, and one vertebra contains the tip end from a typical Folsom point.

While the work at the Lindenmeier site was progressing, Dr. Roberts visited a number of locations in the northern Colorado area where Folsom specimens have been found. None of the latter indicated possibilities for increased knowledge on the subject comparable to those at the Lindenmeier site.

During the month spent in the office Dr. Roberts also worked on manuscripts detailing the results of archeological work conducted in Arizona and at Shiloh National Military Park, Tenn.

From July to October 1934, Dr. W. D. Strong, ethnologist, was in Washington working with the collections made in Spanish Honduras during the preceding years. During the year a report on one phase of this work, entitled "Archeological Investigations in the Bay Islands, Spanish Honduras", was completed. It was published February 12, 1935, in the Smithsonian Miscellaneous Collections, vol. 92, no. 14. In October 1934 Dr. Strong was sent to Fort Collins, Colo., to examine and assist in work at a newly discovered site where a habitation level occupied by Folsom man was being investigated by Dr. F. H. H. Roberts, Jr., of the Bureau of American Ethnology. Returning to Washington in the same month, he was occupied for some time in revising and amplifying an earlier report, "An Introduction to Nebraska Archeology", which was completed and went to press March 1, 1935. From December 1934 until the end of the year, Dr. Strong served as an adviser in anthropology to the Bureau of Indian Affairs. Prior to May 1934 this work was carried on in addition to his other duties but, subsequent to that time, through an arrangement between the Bureau of American Ethnology and the Bureau of Indian Affairs, full time was devoted to this task.

Winslow M. Walker, associate anthropologist, devoted the time from July 1 until the end of the calendar year in working with the collections made in connection with the Federal Civil Works Administration relief project at Buena Vista Lake, Calif. At the same time Mr. Walker was able to continue work in connection with his researches in the lower Mississippi Valley, and completed for publication the report of his work on the large mound at Troyville, La.

J. N. B. Hewitt, ethnologist, was engaged during the year in a revision of the native Onondaga text of the Requickening Address of the Condolence Convocation of the Iroquois League, adding to the text and translation the summarizing speech introductory to the Second Part of this Address, retranslating the whole. He also revised the historical tradition of the founding of the League of the Iroquois, not only words but incidents as well, retranslating the whole to conform to the corrections. Texts of laws relating to other aspects of the League were also revised and made to conform to later information obtained in his researches.

Mr. Hewitt worked on the preparation of a paper analyzing approximately 400 Chippewa place names. He also prepared a list of over 200 Seneca personal names arranged according to the age grades of the individual.

In the course of the year Mr. Hewitt attended the meetings of the Advisory Committee to the Division of Geographic Names of the Department of the Interior, for which he also did some research work.

SPECIAL RESEARCHES

Miss Frances Densmore, a collaborator of the Bureau, continued her study of Indian music during this year, submitting disk records of Indian songs made at the Century of Progress Exposition. The records of seven songs were submitted, with transcriptions of two Navaho and four Sioux songs, and accompanying data. These have been cataloged consecutively with her former work. Two of the Sioux songs were selected by Dean Carl E. Seashore for graphic reproduction by his method of phonophotography, the work being done at his laboratory at the University of Iowa, Iowa City. This is the first use of this technique of graphical recording in connection with the study of Indian music. Dr. Seashore states: "From a single playing before the microphone three groups of records are made: First, a re-recording of the song on hard disks for auditory reference; second, a phonophotographic record of pitch, intensity and time; and, third, an oscillogram for harmonic analysis to determine tone quality." Through his courtesy there was submitted a print of a portion of the original phonophotogram of one of these songs, and a graph, or "pattern score" made by Dr. Harold Seashore from the phonophotogram. A comparison of this score with the transcription made by Miss Densmore corroborates the evidence of the ear in discerning the pitch of Indian singing and also opens interesting new avenues of investigation. Miss Densmore added a chapter on a summary of analysis to her book on British Columbian music, awaiting publication.

Acknowledgment is made of the courtesy of Mrs. Laura Boulton and Dr. George Herzog in providing the use of the Fairchild disk recording apparatus on which Indian songs were recorded at the Century of Progress Exposition.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor. In addition to the current work of the office, considerable progress was made on comparing and correcting the comprehensive manuscript index of Bulletins 1–100 of the Bureau. Every entry is being verified.

An index of Schoolcraft's work entitled "Indian Tribes", in six volumes, begun last year, is well advanced.

Bulletin 112, "An Introduction to Pawnee Archeology", by Waldo Rudolph Wedel, was edited and prepared for printing; and work has been done on other manuscripts in the custody of the editor. Publications distributed totaled 11,955.

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian. The library consists of 31,101 volumes, 17,189 pamphlets, and several thousand unbound periodicals. During the year 400 books were accessioned, of which 47 were acquired by purchase, the remainder being received through gift and exchange of Bureau publications; also 94 pamphlets and 3,125 serials, chiefly the publications of learned societies, were received and recorded. Books loaned during the year numbered 1,069. In the process of cataloging, 1,550 cards were added to the catalog files. Requisition was made on the Library of Congress during the year for 140 volumes for official use. This year, more than in previous years, advantage was taken of the interlibrary loan service for books needed by the staff.

As usual, hundreds of publications were consulted in the library during the year by investigators and students, other than members of the Smithsonian Institution. Individual contributors both at home and abroad continued to show their interest by sending contributions to the library.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator:

Engrossing	1
Line drawings	115
Graphs	43
Photographs retouched	68
Maps	29
Tracings	17
Lettering jobs	147
Plates prepared	97
Photographs colored	21
Mechanical drawings	5
Paintings repaired	2
Total	545

COLLECTIONS

Accession Number

130570. Pottery fragments from Weeden Island, Fla., collected by D. L. Reichard (4 specimens).

130576. Human skeletal material obtained through excavations conducted under the Federal Civil Works Administration by W. M. Walker at various sites in California (88 specimens).

132127. Skeletal material excavated from Peachtree Mound at Murphy, N. C. (39 specimens).

132168. Skeletal material obtained in the course of archeological work conducted at Ormond Beach, Fla., during the winter of 1933–34 under the Federal Civil Works Administration (53 specimens).

133314. Collection of archeological material obtained on the mainland of Spanish Honduras and on the adjacent Bay Islands by Dr. W. D. Strong in 1933 (327 specimens).

134994. Skeletal material from Perico Island, Manatee County, Fla., collected by the C. W. A. during the winter of 1933–34 (180 specimens).

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—The appointment of Winslow M. Walker, associate anthropologist, was terminated May 31, 1935, owing to ill health.

Miss Helen Heitkemper was temporarily appointed as junior stenographer in the absence of Miss Edna Butterbrodt, on furlough.

Respectfully submitted.

M. W. Stirling, *Chief.*

Dr. C. G. Abbot,

Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ended June 30, 1935:

The total appropriation made by Congress for the Service for 1935 was $41,188.17, of which amount $39,692 was included in the regular appropriation act and $1,496.17 was allowed for the purpose of restoring the remainder of the 15 percent economy reduction made in salaries a few years ago. The above is an increase of $2,134.17 in the amount granted for the exchanges during the fiscal year 1934. The repayments from departmental and other establishments aggregated $3,616.05, making the total resources available for conducting the Service during the year $44,804.22.

The total number of packages that passed through the Service during the year was 654,131, a decrease of 21,849. The weight was 560,381 pounds, a decrease of 64,360 pounds.

The publications sent and received are placed under three classes—parliamentary documents, departmental documents, and miscellaneous scientific and literary publications. The number and weight of packages containing the publications coming under these headings are given in the table below.

Class	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	356,591		115,937	
Publications received in return for parliamentary documents		9,033		25,838
United States departmental documents sent abroad	100,420		96,921	
Publications received in return for departmental documents		6,925		26,093
Miscellaneous scientific and literary publications sent abroad	140,405		200,293	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		40,757		95,299
Total	597,416	56,715	413,151	147,230
Grand total handled	654,131		560,381	

The total number of boxes used in dispatching consignments abroad was 2,187, a decrease of 155 from the preceding year. Of these boxes, 460 were for the foreign depositories of full sets of

United States governmental documents and the remainder (1,727) were for distribution to miscellaneous establishments and individuals.

In addition to the packages sent abroad in boxes, 58,873 packages were transmitted directly to their destinations by mail.

In July 1934 a valuable consignment of exchanges, consisting of eight boxes from New South Wales, was destroyed by fire and water on the pier at New York. Five of the boxes contained publications requested by the Institution to complete the collections of official documents of the Government of New South Wales in the Library of Congress. These publications were procured by the Public Library in Sydney, which conducts the Exchange Agency for New South Wales. The Principal Librarian of the Public Library has advised the Institution that he would keep the list of wanted publications in hand and from time to time endeavor again to obtain copies of as many of the documents as are available.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The full set of governmental publications sent to the American Library in Paris has been discontinued, the number of full sets forwarded abroad now being 61. There are 50 depositories of partial sets, making the total number of full and partial sets 111.

Following is a list of full and partial sets of depositories:

DEPOSITORIES OF FULL SIZES

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
- BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)

AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
- NEW SOUTH WALES: Public Library of New South Wales, Sydney.
- QUEENSLAND: Parliamentary Library, Brisbane.
- SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
- TASMANIA: Parliamentary Library, Hobart.
- VICTORIA: Public Library of Victoria, Melbourne.
- WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

AUSTRIA: National-Bibliothek, Wien I.

BELGIUM: Bibliothèque Royale, Brussels.

BRAZIL: Bibliotheca Nacional, Rio de Janeiro.

CANADA: Library of Parliament, Ottawa.
- MANITOBA: Provincial Library, Winnipeg.
- ONTARIO: Legislative Library, Toronto.
- QUEBEC: Library of the Legislature of the Province of Quebec.

CHILE: Biblioteca del Congreso, Santiago.

CHINA: National Central Library, Nanking.

COLOMBIA: Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).
FRANCE: Bibliothèque Nationale, Paris.
GERMANY: Reichstauschstelle im Reichsministerium des Innern, Berlin C 2.
    BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
    BAVARIA: Bayerische Staatsbibliothek, München.
    PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
    SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
    WURTEMBURG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
    ENGLAND: British Museum, London.
    GLASGOW: City Librarian, Mitchell Library, Glasgow.
    LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Imperial Library, Calcutta.
IRISH FREE STATE: National Library of Ireland, Dublin.
ITALY: Ministero dell' Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'Etat, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
MEXICO: Biblioteca Nacional, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: H. M. Stationery Office, Belfast.
NORWAY: Universitets-Bibliotek, Oslo. (Depository of the Government of Norway.)
PERU: Biblioteca Nacional, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Biblioteca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
SPAIN: Servicio de Cambio Internacional, Paseo de Recoletos 20, Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
TURKEY: Ministère de l'Instruction Publique, Ankara.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
UNION OF SOVIET SOCIALIST REPUBLICS: State Central Book Chamber, Moscow 4.
    UKRAINE: All-Ukrainian Association for Cultural Relations with Foreign Countries, Kharkov #2.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Ministry of Foreign Affairs, Publications Department, Kabul.
AUSTRIA:
    VIENNA: Magistrat der Stadt Wien, Abteilung 51-Statistik.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.

Brazil:

Minas Geraes: Directoria Geral de Estatistica em Minas, Bello Horizonte.

Rio de Janeiro: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.

British Guiana: Government Secretary's Office, Georgetown, Demerara.

Bulgaria: Ministère des Affaires Étrangères, Sofia.

Canada:

Alberta: Provincial Library, Edmonton.

British Columbia: Provincial Library, Victoria.

New Brunswick: Legislative Library, Fredericton.

Nova Scotia: Provincial Secretary of Nova Scotia, Halifax.

Prince Edward Island: Legislative Library, Charlottetown.

Saskatchewan: Government Library, Regina.

Ceylon: Chief Secretary's Office (Record Department of the Library), Colombo.

China: National Library, Peiping.

Danzig: Stadtbibliothek, Free City of Danzig.

Dominican Republic: Biblioteca del Senado, Santo Domingo.

Ecuador: Biblioteca Nacional, Quito.

Finland: Parliamentary Library, Helsingfors.

Germany:

Bremen: Senatskommission für Reichs- und Auswärtige Angelegenheiten.

Hamburg: Senatskommission für Reichs- und Auswärtige Angelegenheiten.

Hesse: Universitäts-Bibliothek, Giessen.

Lübeck: President of the Senate.

Thuringia: Rothenberg-Bibliothek, Landesuniversität, Jena.

Greece: Library of Parliament, Athens.

Guatemala: Biblioteca Nacional, Guatemala.

Haiti: Secrétaire d'État des Relations Extérieures, Port au Prince.

Honduras: Biblioteca y Archivo Nacionales, Tegucigalpa.

Iceland: National Library, Reykjavik.

India:

Assam: General and Judicial Department, Shillong.

Bengal: Assistant Secretary to the Government of Bengal, Department of Education, Calcutta.

Bihar and Orissa: Revenue Department, Patna.

Bombay: Undersecretary to the Government of Bombay, General Department, Bombay.

Burma: Secretary to the Government of Burma, Education Department, Rangoon.

Central Provinces: General Administration Department, Nagpur.

Madras: Chief Secretary to the Government of Madras, Public Department, Madras.

Punjab: Chief Secretary to the Government of the Punjab, Lahore.

United Provinces of Agra and Oudh: University of Allahabad, Allahabad.

Jamaica: Colonial Secretary, Kingston.

Liberia: Department of State, Monrovia.

Lithuania: Ministère des Affaires Étrangères, Kaunas (Kovno).

Malta: Minister for the Treasury, Valletta.

Newfoundland: Department of Home Affairs, St. John's.

Nicaragua: Superintendente de Archivos Nacionales, Managua.

Panama: Secretaría de Relaciones Exteriores, Panama.

Paraguay: Secretario de la Presidencia de la Republica, Asunción.

Salvador: Ministerio de Relaciones Exteriores, San Salvador.

SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Rome, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

During the year one additional foreign depository was added to the list of those countries receiving the daily issue of the Congressional Record, the depository being located in Albania.

The two chambers of the National Congress of Cuba having been superseded by a National Assembly with a single chamber, only one copy of the Record is now being forwarded to the Cuban Legislature instead of two. The Records sent to Baden and Mecklenburg-Strelitz were discontinued. There now are 102 copies of the Record forwarded to foreign depositories, a complete list of which is given below:

DEPOSITORIES OF CONGRESSIONAL RECORD

ALBANIA: Ministrija Mibretnore e Punëvetë Jashtme, Tirana.
ARGENTINA:
- Biblioteca del Congreso Nacional, Buenos Aires.
- Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
- Buenos Aires: Biblioteca del Senado de la Provincia de Buenos Aires, La Plata.

AUSTRALIA:
- Library of the Commonwealth Parliament, Canberra.
- NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
- QUEENSLAND: Chief Secretary's Office, Brisbane.
- WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.

AUSTRIA: Bibliothek des Hauses der Bundesgesetzgebung, Wien I.
BELGIUM: Bibliothèque de la Chambre des Représentants, Brussels.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
- Bibliotheca do Congresso Nacional, Rio de Janeiro.
- AMAZONAS: Archivo, Bibliotheca e Imprensa Publica, Manáos.
- BAHIA: Governador do Estado da Bahia, São Salvador.
- ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.
- RIO GRANDE DO SUL: "A Federaçao", Porto Alegre.
- SERGIPE: Bibliotheca Publica do Estado de Sergipe, Aracajú.
- SÃO PAULO: Diario Official do Estado de São Paulo, São Paulo.

BRITISH HONDURAS: Colonial Secretary, Belize.
CANADA:
- Library of Parliament, Ottawa.
- Clerk of the Senate, Houses of Parliament, Ottawa.

CHINA: National Central Library, Nanking.
CUBA: Biblioteca del Capitolio, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DANZIG: Stadtbibliothek, Danzig.
DENMARK: Rigsdagens Bureau, Copenhagen.
DOMINICAN REPUBLIC: Biblioteca del Senado, Santo Domingo.
DUTCH EAST INDIES: Volksraad von Nederlansch-Indië, Batavia, Java.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn (Revel).
FRANCE:
  Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.
  Bibliothèque du Sénat, au Palais du Luxembourg, Paris.
  Bibliothèque, Direction des Accords commerciaux, Ministère du Commerce, Paris.
GERMANY:
  Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
  Reichsfinanzministerium, Berlin W. 8.
  ANHALT: Anhaltische Landesbücherei, Dessau.
  BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
  MECKLENBURG: Staatsministerium, Schwerin.
  OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.
  PRUSSIA: Bibliothek des Preussischen Landtages, Berlin, S. W. 11.
  SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bücheburg.
GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.
GREAT BRITAIN: Library of the Foreign Office, London.
GREECE: Library of Parliament, Athens.
GUATEMALA: Archivo General del Gobierno, Guatemala.
HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Legislative Department, Simla.
IRAN: Library of the Iranian Parliament, Téhéran.
IRAQ: Chamber of Deputies, Bagdad, Iraq (Mesopotamia).
IRISH FREE STATE: Dail Eireann, Dublin.
ITALY:
  Biblioteca della Camera dei Deputati, Rome.
  Biblioteca del Senato del Regno, Rome.
  Ufficio degli Studi Legislativi, Senato del Regno, Rome.
LATVIA: Library of the Saeima, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
LIBERIA: Department of State, Monrovia.
MEXICO: Secretaría de la Cámara de Diputados, Mexico, D. F.
  AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.
  CAMPECHE: Gobernador del Estado de Campeche, Campeche.
  CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
  CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.
  COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
  COLIMA: Gobernador del Estado de Colima, Colima.
  DURANGO: Gobernador Constitucional del Estado de Durango, Durango.
  GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.
  GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.
  JALISCO: Biblioteca del Estado, Guadalajara.
  LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.
  MEXICO: Gaceta del Gobierno, Toluca, Mexico.
  MICHOACÁN: Secretría General de Gobierno del Estado de Michoacán Morelia.
  MORELOS: Palacio de Gobierno, Cuernavaca.
  NAYARIT: Gobernador de Nayarit, Tepic.
  NUEVO LEON: Biblioteca del Estado, Monterey.

OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
PUEBLA: Secretaría General de Gobierno, Puebla.
QUERETARO: Secretaría General de Gobierno, Sección de Archivo, Queretaro.
SAN LUIS POTOSI: Congreso del Estado, San Luis Potosi.
SINALOA: Gobernador del Estado de Sinaloa, Culiacan.
SONORA: Gobernador del Estado de Sonora, Hermosillo.
TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
TAMAULIPAS: Secretaría General de Gobierno, Victoria.
TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
VERA CRUZ: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.
YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets Bibliothek, Oslo.
PERU: Cámara de Diputados, Congreso Nacional, Lima.
POLAND: Ministère des Affaires Étrangères, Warsaw.
PORTUGAL: Secretario da Assemblea Nacional, Lisbon.
RUMANIA:
Bibliothèque de la Chambre des Députés, Bucharest.
Ministère des Affaires Étrangères, Bucharest.
SPAIN:
Biblioteca del Congreso Nacional, Madrid.
SWITZERLAND:
Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
SYRIA:
Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
Governor of the State of Alaouites, Lattaquié.
TURKEY: Turkish Grand National Assembly, Ankara.
UNION OF SOUTH AFRICA:
Library of Parliament, Cape Town, Cape of Good Hope.
State Library, Pretoria, Transvaal.
URUGUAY: Biblioteca del Poder Legislativo, Montevideo.
VENEZUELA: Biblioteca del Congreso, Caracas.
VATICAN CITY: Biblioteca Apostolica Vaticana, Rome, Italy.

FOREIGN EXCHANGE AGENCIES

There is given below a list of the agencies abroad through which the distribution of exchanges is effected. Many of the agencies forward consignments to the Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.
ANGOLA, via Portugal.
ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Callao 1540. Buenos Aires.
AUSTRIA: Internationale Austauschstelle, National-Bibliothek, Wien, I.
AZORES, via Portugal.
BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANADA: Sent by mail.

CANARY ISLANDS, via Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, National Central Library, Nanking.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Sent by mail.

CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.

DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Press, Publications Office, Bulaq, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn.

FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 2–4 Arthur St., New Oxford St., London, W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

ICELAND, via Denmark.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Uyeno Park, Tokyo.

JAVA, via Netherlands.

KOREA: Sent by mail.

LATVIA: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LITHUANIA: Sent by mail.

LOURENÇO MARQUEZ, via Portugal.

LUXEMBOURG, via Belgium.

MADAGASCAR, via France.

MADEIRA, via Portugal.
MEXICO: Sent by mail.
MOZAMBIQUE:, via Portugal
NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: General Assembly Library, Wellington.
NICARAGUA: Ministerio de Relaciones Exteriores, Managua.
NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
PALESTINE: Hebrew University Library, Jerusalem.
PANAMA: Sent by mail.
PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Asunción.
PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
PORTUGAL: Secção de Trocas Internacionaes, Bibliotheca Nacional, Lisboa.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid.
SUMATRA, via Netherlands.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
SYRIA: American University of Beirut.
TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS: via France.
TURKEY: Robert College, Istanbul.
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Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk.

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1935:

The regular appropriation made by Congress for the maintenance of the Park was $189,600. This was increased by $9,396 by special act of Congress to provide for salary restoration.

ACCESSIONS

Gifts.—A number of important gifts during the year enriched the collection appreciably. A serval and a caracal, gifts to President Franklin D. Roosevelt, were turned over to the Park. Russell M. Arundel, Washington, D. C., presented a bushmaster. Two of the rare Hood Island tortoises were received from the San Diego Zoological Garden. Through the interest of O. H. Johnson, of Pierre, S. Dak., four prong-horned antelope were received from the South Dakota Game and Fish Commission. Roy H. Jennier, of the Zoo staff, brought from Panama an interesting collection of reptiles, gifts from Dr. James Zetek and Douglas D. H. March.

DONORS AND THEIR GIFTS

Amazonica, Inc., New York City, 2 common boas.
Russell M. Arundel, Washington, D. C., bushmaster, 13 black-widow spiders.
Hugh D. Auchincloss, Jr., Washington, D. C., 3 alligators.
P. W. Austin, Washington, D. C., red-shouldered hawk.
Dr. Paul Bartsch, Washington, D. C., Franklin's spermophile.
Baltimore County Humane Society, rhesus monkey.
Joan T. and Joseph F. Beattie, Washington, D. C., 4 collared lizards.
D. F. Berry, Orlando, Fla., coral snake.
Mrs. E. Jason Black, Washington, D. C., Burmese mongoose.
Mrs. John S. Bleeker, Washington, D. C., alligator.
Maurice Brady, Washington, D. C., 3 salamanders.
S. K. Brown, Eustis, Fla., 2 coral snakes, hog-nosed snake, corn snake.
Dr. W. A. Brumfield, Farmville, Va., great horned owl, hog-nosed snake.
Harley B. Buckingham, Takoma Park, Md., woodcock.
Mrs. Louise Burke, Washington, D. C., red-breasted finch.
Dr. C. E. Burt, Winfield, Kans., 10 horned lizards, 2 indigo snakes, 3 green racers, bald eagle, 18 brown skinks, 4 six-lined racers, 21 collared lizards.
Tom Cargill, Washington, D. C., 2 garter snakes.
Caribbean Biological Supply Laboratories, Biloxi, Miss., 2 robust plated lizards, blue-tongued lizard, stump-tailed lizard, 6 Australian tree frogs.

C. C. C. Camp, Grottoes, Va., 4 pine snakes.
Mr. Childress, New Market, Va., prairie dog.
Dr. Doris M. Cochran, Washington, D. C., 2 tree porcupines.
Miss Conrad, Washington, D. C., 2 grass parakeets.
Costello M. Craig, Washington, D. C., 7 water snakes, pilot snake, queen snake, 9 copperhead snakes, 2 banded rattlesnakes, 3 blacksnakes.
E. A. Cuevas, Washington, D. C., 3 black-widow spiders.
T. W. Currier, Washington, D. C., barred owl.
Ned Dearborn, Washington, D. C., Congo eel.
F. A. Dowell, Cheverly, Md., Florida gallinule.
Messrs. East and W. Perrygo, Washington, D. C., black-widow spider, blacksnake.
Elliott Eccard, Washington, D. C., barn owl.
Mr. Elliott, Washington, D. C., sparrow hawk.
Dr. Wm. O. Emery, Washington, D. C., midwife toad.
Miss Charlotte Ericson, Hyattsville, Md., yellow-naped parrot.
L. E. Eward, Washington, D. C., Pekin duck.
Mrs. Fair, Washington, D. C., raccoon.
Postmaster General James A. Farley, Washington, D. C., 3 horned lizards, box tortoise.
Frank M. Fields, Washington, D. C., tarantula.
Fire Department, Alexandria, Va., rhesus monkey.
Florida Reptile Institute, Silversprings, Fla., 7 Florida diamondback rattlesnakes, 4 water snakes.
A. Foehl, Jr., Philadelphia, Pa., great land crab.
Mrs. Frank, Anacostia, D. C., alligator.
R. H. Gallahan, Alexandria, Va., gopher turtle.
Lt. Col. C. C. Gee, Washington, D. C., hog-nosed snake.
Miss Constance Grady, Washington, D. C., Pekin duck.
J. A. Haeseler, New York City, 3 Florida cormorants, Florida otter.
C. C. Hagenbuch, Washington, D. C., bullsnake.
H. P. Harnberger, Washington, D. C., 11 copperhead snakes.
W. B. Harrison, Wildwood, Fla., worm lizard.
Ralph Henderson, Washington, D. C., pied-billed grebe.
Hershey Zoo, Hershey, Pa., golden eagle, 4 red-tailed hawks.
G. Hickman, Washington, D. C., woodchuck.
Wayne Hill, Washington, D. C., double yellow-head parrot.
W. H. Hoffman, Washington, D. C., salamander.
Miss Dorothy Hood, Washington, D. C., common boa.
Dr. Hopkins, Washington, D. C., white-throated capuchin.
Dr. L. R. House, Washington, D. C., opossum.
Clyde Ingalls, Ringling Bros.-Barnum & Bailey Circus, pine snake.
Capt. James Jalickee, Washington, D. C., snapping turtle.
Stuart W. Jenks, Washington, D. C., garter snake, 2 blacksnakes, 2 coachwhip snakes, 2 hog-nosed snakes, 2 Florida king snakes.
J. C. Johnson, Washington, D. C., skunk.
Children of the Jones Family, Eastern Star Home, Washington, D. C., 2 alligators.
Mrs. A. S. Jones, and Miss Mary E. North, Washington, D. C., Hamadryas baboon.
Carl F. Kauffeld, New York City, red-bellied turtle.
Mr. Kidwell, Vienna, Va., red fox.
H. H. King, Washington, D. C., banded rattlesnake.
Douglas Knight, Washington, D. C., blacksnake, garter snake.

Dr. W. H. Krull, Washington, D. C., pilot snake.
Robert H. Lake, Takoma Park, Md., woodchuck.
W. K. Lawlor, Washington, D. C., copperhead snake.
Dr. Camille L'Herisson, Port-au-Prince, Haiti, Haitian boa.
Otto Martin Locke, New Braunfels, Tex., 28 horned lizards.
C. C. Logan, Luray, Va., banded rattlesnake.
Mrs. Charles MacFarland, Washington, D. C., woodchuck.
Douglas D. H. March, Panama City, Panama, common iguana, rainbow boa, Mexican boa, southern ctenosaur.
Dr. Cloyd Heck Marvin, Washington, D. C., 3 golden pheasants.
Joseph Mathy, Washington, D. C., sparrowhawk.
John May, Washington, D. C., ring-necked pheasant.
Wm. McClure, Washington, D. C., flying squirrel.
E. A. McIlhenny, Avery Island, La., 17 snowy herons, 22 Louisiana herons, 4 anhingas, 3 little blue herons.
Dr. A. L. Melander, Riverside, Cal., Agassiz's tortoise.
Dr. Fofo Mezitis, Washington, D. C., 2 little green herons.
H. Mers, Washington, D. C., alligator.
Michigan State Parks, thru' P. J. Hoffmaster, 3 beavers.
Gerrit S. Miller, Jr., Washington, D. C., macaque monkey.
J. C. Moore and A. K. Sonner, Washington, D. C., 2 timber rattlesnakes.
Mrs. S. G. Morley, Carnegie Institution, Washington, D. C., 2 Costa Rican deer.
Mrs. Murray, Washington, D. C., grass paroquet.
National Institute of Health, Washington, D. C., rhesus monkey.
Mrs. Joseph Oser, Washington, D. C., alligator.
R. G. Paine, Washington, D. C., hoop or rainbow snake, pilot snake, corn snake.
L. V. Pearson, Clarendon, Va., ring-necked pheasant.
F. A. Peckham, Washington, D. C., water snake, ring-necked snake.
Miss V. L. Philhower, Washington, D. C., grass parakeet.
Charles L. Pilzer, Washington, D. C., barred owl, 2 rabbits.
Igor Plansky, Washington, D. C., boa.
Freeman Pollock, Skyland, Va., timber rattlesnake.
Mrs. G. F. Pollock, Washington, D. C., 2 tovi paroquets.
R. Ralston, Alexandria, Va., false chameleon.
A. Randon, Berwick, Pa., blacksnake.
David Rawlings, Kensington, Md., copperhead snake.
Howard Reed, Washington, D. C., tarantula.
Lawrence Reid, Langley, Va., barn owl, red-tailed hawk.
Miss L. Reuter, Washington, D. C., white-faced capuchin.
L. T. Riddle, Washington, D. C., 2 prairie dogs.
A. P. Robbins, Chevy Chase, Md., turtle.
C. E. Roberts, Washington, D. C., red-shouldered hawk.
Beverly Rodgers, Washington, D. C., screech owl.
Cornelius R. Rogers, Lake City, Kans., 12 horned lizards.
President Franklin D. Roosevelt, The White House, serval and caracal.
Jack Rowell, Rixeyville, Va., red fox.
Mrs. E. Ruff, Washington, D. C., marine turtle.
Louis Ruhe, Inc., New York City, golden cat.
Dr. Herbert Sanborn, Nashville, Tenn., broad-winged hawk.
San Diego Zoological Park, San Diego, Calif., 2 Hood Island tortoises.
George Schreyer, Washington, D. C., barn owl.
Charles Selby, Washington, D. C., coachwhip snake, bullsnake, green racer, milk snake, 4 hog-nosed snakes.

Mrs. Charles Shelby, Washington, D. C., 5 bullsnakes.
Gates Slattery, Washington, D. C., red-tailed hawk.
Miss Edith Smallwood, Cumberland, Md., green guenon.
South Dakota Game & Fish Commission, through O. H. Johnson, Pierre, S. D., 4 prong-horn antelopes.
Dr. Robert M. Stabler, Philadelphia, Pa., woodchuck.
Franklin A. Thompson, Washington, D. C., 2 ring-necked snakes, water snake.
M. I. Tomilin, Orange Park, Fla., garter snake, 2 hog-nosed snakes, coachwhip snake, water moccasin or cottonmouth, 5 water snakes.
U. S. Biological Survey, Washington, D. C., pintail.
U. S. Biological Survey, through J. S. C. Boswell, Canada Goose, corn snake, 3 king snakes; through J. M. Hill, Jr., and L. C. Whitehead, 28 white-necked ravens; through F. C. Lincoln, ring-necked pheasant; through George Mushbach, 2 cinnamon teals; through Utah State F. E. R. A., 3 pumas.
U. S. Bureau of Fisheries, through Fred Orsinger, 6 mudpuppies.
W. H. Vesper, Washington, D. C., 2 kinkajous.
Mrs. L. C. Vogt, Takoma Park, Md., canary.
Mrs. Reginald Walker, Washington, D. C., common turkey, mallard duck.
Mrs. Carl Werthner, Washington, D. C., sulphur-crested cockatoo.
Miss E. J. Whitacre, Washington, D. C., double yellow-head parrot.
Mrs. Hazel Whitaker, Takoma Park, Md., sulphur-crested cockatoo.
J. O. Whittey, Washington, D. C., marine turtle.
K. F. Wood, Washington, D. C., screech owl.
John F. Wynkoop, Washington, D. C., Virginia opossum.
Dr. James Zetek, Canal Zone, Panama, 60 arrow-poison frogs, 12 yellow atelopus.
Vincent Zoll, Washington, D. C., 4 Siamese fighting fish.
Donor unknown: Boa.

Exchanges.—Notable additions obtained through the medium of exchange were an Asiatic wild ass or Kiang, black-buck or Indian antelope, and a barking or rib-faced deer obtained from Hagenbeck Brothers, Hamburg, Germany. From the Philadelphia Zoological Garden were received 2 electric eels. A pair of zebu were obtained from Ellis S. Joseph, New York City.

Purchases.—Important purchases during the year were 3 Siberian ibex and 3 Saiga antelopes, the first of their kind ever exhibited in the Park.

Births.—There were 42 mammals born in the Park during the year. These include the following:

MAMMALS

Scientific name	Common name	*No.*
Axis axis	Axis deer	1
Bison bison	American bison	3
Bos indicus	Zebu	1
Canis nubilius	Plains wolf	3
Cervus duvaucelii	Barasingha deer	2
Cervus elaphus	Red deer	2
Dama dama	Fallow deer	4
Dolichotis salinicola	Dwarf cavy	1
Equus quagga chapmani	Chapman's zebra	1

MAMMALS—continued

Scientific name	Common name	No.
Equus zebra	Mountain zebra	1
Felis concolor	Puma	4
Lama glama	Llama	5
Macaca mulatta	Rhesus monkey	1
Odocoileus virginianus	Virginia deer	3
Ovis europaeus	Mouflon	1
Sika nippon	Japanese deer	6
Taurotragus oryx	Eland	1
Thalarctos maritimus × Ursus gyas	Hybrid bear	2

REMOVALS

Deaths.—Important losses by death during the year include 4 jackass penguins; a dusky or crested langur; secretary bird; Siberian tiger, autopsy on which showed the cause of death to be chronic gastro-enteritis. A young male orangutan died of pneumonia. A female Saiga antelope died of a broken neck, the result of running into the paddock fence when the animal became frightened. An aardvark received May 22, 1934, died April 4, 1935.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	Common name
Capra sibirica	Siberian ibex.
Felis temmincki	Golden cat.
Herpestes birmanicus	Burmese mongoose.
Saiga tatarica	Saiga antelope.
Sciurus finalysoni	Lesser white squirrel.

BIRDS

Anorrhinus galeritus	Sumatran dusky hornbill.
Cinnyris habessinicus	Abyssinian sun bird.
Dicrurus mirabilis	White-bellied drongo.
Falco albigularis	White-throated bat falcon.
Phoeniculus somaliensis	Black-billed wood hoopoe.
Polihierax semitorquatus	African pigmy falcon.
Scopus umbretta	Hammerhead.

REPTILES

Dendrobates auratus	Arrow-poison frog.

Statement of the collection

Class	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	42	42	11	13	9	117
Birds	127		12	64	5	208
Reptiles	146		3	51	4	204
Amphibians	66					66
Fishes	10			10		20
Arachnids	10					10
Insects						
Crustaceans	1					1
Mollusks	1					1
Total	403	42	26	138	18	627

Summary

Animals on hand July 1, 1934	2,238
Accessions during the year	627
Total animals in collection during year	2,865
Removal from collection by death, exchange, and return of animals on deposit	695
In collection June 30, 1935	2,170

Status of collection

Class	Species	Individuals	Class	Species	Individuals
Mammals	171	509	Arachnids	1	4
Birds	315	946	Insects	1	40
Reptiles	131	413	Crustaceans		
Amphibians	25	107	Mollusks	1	3
Fishes	20	148	Total	665	2,170

Little attempt was made to replace the smaller mammals for which there are no exhibition quarters, but although the collection is somewhat smaller in specimens, the quality has improved.

VISITORS FOR THE YEAR

July	246,350	February	63,250
August	224,650	March	171,110
September	183,950	April	293,739
October	177,400	May	219,600
November	114,900	June	259,600
December	59,750		
January	31,850	Total	2,046,149

The attendance of organizations, mainly classes of students, of which there is definite record was 29,024 from 394 different schools in 20 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Connecticut	236	3	New York	3,322	23
Delaware	49	1	North Carolina	675	20
District of Columbia	5,890	107	Ohio	610	8
Florida	28	1	Pennsylvania	7,176	29
Georgia	236	7	Rhode Island	38	1
Indiana	96	1	South Carolina	155	5
Maine	111	2	Tennessee	95	2
Maryland	3,699	59	Virginia	3,418	74
Massachusetts	163	5	West Virginia	87	3
Minnesota	69	1	Magicians of United States	47	1
New Jersey	2,798	40			
New Mexico	26	1	Total	29,024	394

About 2 o'clock almost every afternoon a census is made of the cars parked on the Zoo grounds. During the year 53,877 were so listed, representing every State in the Union, Hawaii, Philippine Islands, Canal Zone, the Bahamas, Cuba, Alaska, Canada, and Mexico. Since the total number is merely a record of those actually parked at one time, it is not of value as indicating a total attendance but is of importance as showing the percentage attendance by States, Territories, and countries. The District of Columbia comprised only a little over 32 percent; Maryland 14 percent; Virginia 5 percent, and the remaining cars were from other States, Territories, and countries.

Each year increased use is made of the Zoo's facilities by students, artists and modelers, for motion-picture photography, recording of sounds made by animals for phonograph records, and other studies. Numerous clubs and societies visit the Zoo as part of their programs.

IMPROVEMENTS

The outstanding improvements of the year were made possible by funds from the Public Works Administration and labor and materials from the Emergency Works Administration.

On January 26, 1935, an allotment was made by the Public Works Administration of $680,000 for the construction of a small mammal house, a pachyderm house, an addition to the bird house, and mechanical shops in the Zoo. Edwin H. Clarke, an architect who has specialized in zoo construction, was engaged to take charge of the designing and construction of these buildings. The work of preparing plans and specifications for these structures was at once started in the Office of the Supervising Architect with Mr. Clarke consultant in charge. The completion of these projects will be one of the most important single events in the history of the Zoo since its foundation, for it will provide some of the structures most urgently needed for many years.

The accomplishments with the Emergency Works Administration men and materials were gratifying. For the most part, these consisted of finishing work that was started and left incomplete when the C. W. A. activities ceased at the end of March 1934, and the carrying on of similar work. The more important pieces of work completed were: Finishing of the mountain-sheep mountain and erection of fence around it; completion of the condor cage; completion of a frame building 40 by 22 feet for the wild-horse group; pouring of a concrete foundation for another similar building and the moving of a previously built structure onto this foundation; finishing of the pouring of terrazzo floors in the lion house and the grinding of terrazzo floors in the entire structure, including the

grinding of drains in front of the cages; grinding of 75 linear feet of terrazzo gutter in the floor of the bird house; completion of a stone building 15 by 88 feet, roofing of same, construction of dens in the building and cages outside for the housing of hardy outdoor animals of medium size (this structure is known as the outdoor Cat House and replaces a group of unsightly dilapidated cages formerly on this site); construction of 800 linear feet of stone wall, grading and planting adjacent to the Cat House; construction of a concrete pool of irregular shape 20 by 60 feet and 2 feet in depth, partially surrounded by a shallow moat, low concrete wall and guard rail (for swans, cormorants, and pelicans), and planting of trees and shrubbery adjacent thereto; construction of a stone wall to retain and protect the high bluff at the south end of the eagle flight cage and planting of shrubbery thereon; surfacing with broken concrete and stone of 2,500 square yards of hillside road excavated under C. W. A. and the placing of 1,000 linear feet of Belgian block gutter at the edge of this road; construction of two double and six single rustic drinking fountains with terrazzo bowls and installation of these about the park; considerable painting; grounds improvement consisting of removal of perennial weeds from lawns, making of minor fills, seeding with grass seed, removal of excess shrubbery, including an intensive campaign against poison ivy, removal of dead trees and limbs that were dangerous over about 100 acres of the park; planting of a few trees and shrubs, with the result that the grounds are now in much better condition than ever before.

In addition to the materials furnished by the E. W. A., materials were purchased from park funds so far as possible for use by the labor assigned by the E. W. A., and in this manner the accomplishments were of much more lasting benefit than would otherwise have been possible.

This opportunity is taken to place on record our keen appreciation of the valuable and cordial assistance rendered by the District E. W. A. officials, particularly Capt. Howard F. Clark and William C. Cleary.

Through the cooperation of W. L. Corbin, Smithsonian librarian, the Zoo was permitted to select from the considerable mass of surplus publications accumulated by the Institution a large number of volumes and pamphlets on vertebrate zoology that will be valuable additions to the Zoo library. Also through his office, arrangements were made with the officials of the Library of Congress for the Zoo library to select a number of publications that will be useful. The repairing, cataloging, accessioning, and filing of these publications in the Zoo library remains to be done.

NEEDS OF THE ZOO

Some of the greater needs in equipment for the Zoo have been supplied through Public Works funds and the Federal Emergency Relief Administration. There is still a need for more liberal appropriations for the purchase of specimens; the Zoo has always been handicapped by the small amount available for this purpose.

Respectfully submitted.

W. M. MANN, *Director*.

DR. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1935:

This observatory comprises: (*a*) The central station at Washington where apparatus is made and standardized; where reports are computed, written, and published; where preparations for expeditions are made; and where a general oversight is maintained of the field stations. (*b*) A station on Mount Wilson, near Pasadena, Calif., where brief expeditions for special researches go from time to time. (*c*) A station on Table Mountain near Swartout, Calif., where daily observations of the solar constant of radiation are carried on. (*d*) A similar solar-constant station on Mount Montezuma, near Calama, Chile. (*e*) A similar station on Mount St. Katherine near Mount Sinai, Egypt. These stations are supported principally by annual Government appropriations, but in a considerable part by private funds.

REVISION OF SOLAR-CONSTANT METHODS

Records of daily observations at Mount St. Katherine since December 1933 being available, a complete reduction of them was undertaken by the assistant director, L. B. Aldrich. Additional assistance was generously made available under a grant from John A. Roebling, so that at times as many as six computers assisted Mr. Aldrich in this work. By these means he was able to compute numerous "long method" values of the solar constant of radiation, base thereon a suitable "short method" of reduction, and compute so many values by the short method as to show that the Egyptian station bids fair to prove of high excellence. Although the complete computation of all available days would not be finished before August 1935, Mr. Roebling was so far pleased and satisfied with the results from Mount St. Katherine, and so impressed with the need of this cooperating station, that in June 1935 he made a further grant to finance its occupation as a solar radiation station until 1938. At the same time he provided for a revision and extension of "short method" tables for the stations at Montezuma, Chile, and Table Mountain, Calif., which will be undertaken as soon as the work of reduction for Mount St. Katherine is completed. It is pleasant to recall that the project

of a station in the Old World was initiated under a grant from the National Geographic Society. The outfit at Mount St. Katherine, originally employed at Mount Brukkaros, Southwest Africa, is the gift of the National Geographic Society.

Mr. Roebling also made it possible to send W. H. Hoover with supplies to inspect the stations at Montezuma and Mount St. Katherine, and to install there improved pyrheliometric apparatus. The apparatus referred to is a specially constructed pyrheliometer of the Ångström type. It is to be read as often as possible during bolometric observations, and is to be calibrated daily, or nearly so, against the Abbot silver-disk pyrheliometers heretofore used for daily solar radiation observing. In this way the advantage of the smaller accidental error of the Ångström type instrument will be combined with the long-continued stability of scale of the silver-disk pyrheliometer. It is believed that the accuracy of the daily values of the solar constant will be decidedly enhanced by this improved apparatus, and by the revised short method tables. Mr. Hoover visited the Montezuma station in February and March 1934, and will go out to Egypt in September or October 1935. During his stay at Montezuma all parts of the apparatus and methods were rechecked, and several improvements were made.

The new apparatus above referred to was prepared by the observatory instrument maker, A. Kramer, and the fine electrical devices therein by L. B. Aldrich.

PERIODICITIES IN SOLAR VARIATION AND WEATHER

Studies of the periodicities which superposed make up the variation of the solar radiation were continued by Dr. Abbot, with the assistance, as computer, of Miss L. B. Simpson, under a grant from Mr. Roebling. Using the best available monthly mean values of the solar constant from 1920 to 1934, inclusive, additional periodicities of 9¾, 34, 39½, 92, and 276 months were found in the variation of solar radiation besides the seven formerly discovered of 7, 8, 11, 21, 25, 46 and 68 months respectively. All 12 are approximately integral submultiples of 23 years. A synthesis of these 12 periodic variations in the solar radiation was made. The synthesis represents the original values to within an average deviation of $^{13}/_{100}$ of 1 percent.

Two 2-year forecasts of solar variation were prepared in 1930 and 1932, and were approximately verified by the event. The maxima and minima were nearly correctly forecasted as to time, but the curve of observation separated toward the end, as well as in 1932, from the curve of forecast. These defects seem likely to be corrected by the new analysis, and a forecast for 3 years in advance has been ventured.

Having so satisfactorily analyzed the variation of the sun, Dr. Abbot has sought to detect the influence of the newly discovered solar variations on weather. For this purpose he analyzed the prolonged records of departures from normal for temperature and precipitation for the stations Helsingfors, Berlin, Copenhagen, Greenwich, Cape Town, and Adelaide. Monthly mean departures were computed from "World Weather Records" (recently published by the Smithsonian Institution under grants from Mr. Roebling). For greater simplicity the departures were smoothed by 5-month traveling means. They were then analyzed to detect the solar periodicities above listed, and any others which might be disclosed.

As a result Dr. Abbot was convinced that all the 12 solar periodicities named above except that of 39½ months, and in addition several others, viz, 13.6, 55, and 138 months, occur in both temperature and precipitation at all stations investigated. But changes of phase in the periodicities were found to occur occasionally. An important regularity in these changes of phase was discovered. They are apt to occur abruptly at times which are integral multiples of 11½ years, or still more frequently of 23 years after January 1819.

Having discovered the importance of the cycle of 23 years, both as least common multiple of all periodicities disclosed in the variation of the sun and the weather, and also as a master key to changes of phase in weather periodicities, the next step was to inquire if this cycle appears in the levels of lakes and streams, the life cycles of animals and plants, and in other terrestrial phenomena related to weather. On investigation, the 23-year cycle was disclosed in the level of the Nile for 600 years, the levels of the Great Lakes since 1837, the catch of cod and mackerel since 1812, the rainfall of southern New England since 1750, the thickness of tree-rings in many localities and over many centuries, and in varves of Pleistocene and Eocene geologic time.

Finally, on plotting the temperature and precipitation of more than 30 stations distributed over the United States, numerous detailed features which appeared in a cycle of 23 years seemed to repeat themselves, though with some modifications of phase and amplitude, in successive cycles of 23 years. Assuming that this phenomena will continue, forecasts for the 30 or more stations for 1934, 1935, and 1936 were prepared, based on the weather of the preceding half century or more. The year 1934 has now elapsed, and the forecast for that year has been compared with the event. The predictions for 1934 have been grouped in four grades of success in the forecasts both of temperature and precipitation. They are: A, excellent, showing a close accord throughout the year; B, good, nearly as satisfactory; C, accordant half the time; D, bad, showing complete dis-

agreement. Of 66 forecasts, including 31 of temperature and 35 of precipitation, 27 percent are of grade A, 42 percent of grade B, 17 percent of grade C, and 14 percent of grade D.

Reverting to the levels of the Great Lakes, not only the 23-year cycles, but apparently the double cycle of 46 years is of great importance. It appears to be associated with the drought which has occurred in the northwest-central States since about 1930. It is, of course, plain that the low lake levels are subject to a lag of perhaps 3 years behind the drought conditions which cause them. Hence recovery may be expected several years before the return of the lakes to normal levels.

FIELD WORK

Observations of the solar radiation have gone on regularly at Table Mountain, Calif., Montezuma, Chile, and Mount St. Katherine, Egypt. Besides the solar observatories, Mr. Butler, field director at Montezuma, at his own initiative, has continued for several years highly valuable seismographic observations there in cooperation with the United States Coast and Geodetic Survey. Also, the assistant at Montezuma, Mr. Maltby, has undertaken certain cosmic ray work in cooperation with the Massachusetts Institute of Technology.

For several years the observers at Table Mountain, Calif., carried on regular daily and nightly measurements of astronomical " seeing " to assist in selecting the best location for the 200-inch telescope of the California Institute of Technology. The " seeing " at Table Mountain proved to be of the highest excellence. The observations are now discontinued.

The expedition of Messrs. Abbot and Aldrich to Mount Wilson, referred to in last year's report, proved less successful than was at first thought. The comparison of silver-disk pyrheliometers with the standard water-flow instrument indeed was highly successful, and a paper thereon has been published. But the investigation of the extreme infrared solar spectrum, although incidentally leading to a great improvement in the kampometer, a very sensitive radiation instrument, requires further improvements of apparatus for success. Observations were undertaken in cooperation with Dr. Joel Stebbins on the energy spectra of the stars. In this experiment the stellar spectral rays were selected by a battery of Christiansen filters, and the intensities were measured by means of the Stebbins photoelectric cell. Though apparently promising, the results were found to be vitiated by stray light. This occurred because the photoelectric cell is so disproportionately sensitive at certain wave lengths. It will be necessary to substitute some other receiver, as for instance the thermoelectric cell, if energy spectra of the stars are to be observed.

PERSONNEL

No change has occurred in the regular personnel. Temporary computers under Roebling grants have been employed, including the Misses L. B. Simpson and Frances Holly, Mrs. F. E. Fowle, and E. S. Chappell, Jr.

SUMMARY

Regular observations of the solar constant of radiation have been continued daily when possible at Table Mountain, Calif., Montezuma, Chile, and Mount St. Katherine, Egypt. Improvements in instrumental equipment and in methods have been made tending to increase the accuracy of the daily results. Reductions almost completed, including tables required in future reductions, have been computed for Mount St. Katherine. They seem to indicate that the station will be nearly, if not quite, on a par with our best station, Montezuma. Through the generosity of John A. Roebling, it is arranged to continue the Mount St. Katherine station to 1938. Analysis of solar variation since 1920 has revealed 12 periodicities, all approximately aliquot parts of 23 years. Their summation reproduces the entire solar variation to an average agreement within ⅕ of 1 percent. These 12 periodicities, with three more not as yet found in solar variation, but all approximately aliquot parts of 23 years, are found in temperature and precipitation records for six terrestrial stations for the past century. Inversions and changes of phase occur, but these are found to take place at integral multiples of 11½ years measured from 1819. The 23-year cycle, which Hale found in the magnetic polarity of sun spots, is found in the levels of lakes and streams, the widths of tree-rings, the catches of ocean fish, varves of Pleistocene and Eocene geologic age, and other phenomena depending on weather. Numerous repetitive identifiable features occur in temperature and precipitation within each 23-year cycle. Forecasts of both elements for 1934, 1935, and 1936 for over 30 stations in the United States have been made. Satisfactory agreement between forecasts and the events have been found for about two-thirds of the stations during 1934. It has not been deemed wise to publish the forecasts until further tested.

Respectfully submitted.

C. G. Abbot, *Director*.

The Secretary,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ended June 30, 1935:

It is a pleasure to acknowledge further financial support for the Division during the past year from the Research Corporation of New York.

An important improvement of the Christiansen filters used for selecting desired spectral rays for carrying on plant growth experiments was perfected. The difficulty hitherto has been that when powerful beams of white light enter a Christiansen filter, the central parts of the filter, farthest from the control of the water jacket, rise considerably above the temperature of control. This spoils the selective properties of the filter and gives rise to a broad, indefinite spectral band. The defect was remedied by inserting parallel with the transmitted beam a grill of thin aluminum strips intimately in contact with the outer wall of the filter. In this way, without much loss of light, the excess heat at the center is conducted away and the selective properties are greatly improved.

Christiansen filters thus equipped have been used to repeat experiments on the dependence of the growth of algae and of wheat on the wave length of radiation. In the experiments on wheat a further improvement was made by setting up the great coelostat referred to in the Smithsonian Report for 1903, constructing for use with it a pair of very large Christiansen filters and using sunlight in place of electric light, thus multiplying the available intensities. By controlling the temperature of the water jacket it was then possible to select from the solar spectrum any desired color from the extreme red to the deep violet.

With these improvements, studies of wave-length influence on the growth of unicellular algae and on photosynthesis of wheat have been repeated with great success, much improving earlier results. The study of the lethal effects of ultraviolet rays on unicellular algae has also been repeated and carried to a wave length of 2,250 Ångströms, with highly accurate results. Further experiments in phototropism are in progress, and new results of especial interest

seem to have been found. Growth of tomato plants under control as to temperature, humidity, and color and intensity of radiation are in progress. The interesting and important observation was made that these plants require a resting period at cooler temperature as well as darkness.

In cooperation with the United States Department of Agriculture, experiments were made and published on the promotion and inhibition of the germination of seeds under different selected wave lengths of light.

An experiment on the growth of wheat under out-of-door conditions with controlled quantities of carbon dioxide was carried through with satisfactory results.

Absorption spectral apparatus has been adjusted for use.

A number of papers embodying the results of all of the abovementioned experiments were published during the year, and others are in preparation for publication.

Personnel.—No changes occurred, except that Dr. Enoch Karrer was employed temporarily.

Respectfully submitted.

C. G. Abbot, *Director.*

The Secretary,
Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1935:

THE LIBRARY

The library of the Smithsonian Institution is in reality a library system, for it is composed of 45 libraries, each related to the work of the Institution as a whole or to that of one of its branches. Outstanding among them in point of age, size, and importance of material are the Smithsonian deposit in the Library of Congress and the libraries of the United States National Museum and the Bureau of American Ethnology. The other members of the system are the libraries of the Astrophysical Observatory, Freer Gallery of Art, National Gallery of Art, National Zoological Park, the Langley aeronautical library, radiation and organisms library, Smithsonian office library, and the 35 highly specialized sectional libraries of the National Museum. The libraries, taken together, number nearly 850,000 volumes, pamphlets, and charts.

PERSONNEL

Margaret Moreland, senior stenographer and secretary in the office of the librarian, resigned to accept a position in New York. The vacancy was filled by the transfer, from the examining division of the Civil Service Commission, of Lucile A. Torrey, an A. B. from Tulane University and a B. S. in library science from the Louisiana State University, with stenographic training.

Grace A. Parler, who since 1930 had been on temporary appointment as under library assistant in the Freer Gallery of Art, was made a permanent member of the staff and advanced in grade.

Bruce Middleton resigned the position of minor library assistant in the Astrophysical Observatory to accept promotion in the Department of Agriculture.

A temporary position of minor library assistant was established in the National Zoological Park and filled for 3 months.

The temporary employees were Clarence Athearn, Alice Elizabeth Hill, Margaret Link, Grace A. Parler, and Helen Rankin. There

were also for varying periods during the year several student assistants, including one assigned to the library by the school of library science of Simmons College, and a number of F. E. R. A. workers.

EXCHANGE OF PUBLICATIONS

The exchange work of the library continued much as usual. The number of packages, each of one or more publications, that came by mail was 20,376—a gain of 332 over 1934; and through the International Exchange Service, 1,880—a loss of 96. Of especial value to the Smithsonian deposit and the library of the National Museum were the sendings from the Arctic Institute, Leningrad; the Franklin Institute, Philadelphia; the Peabody Museum, Cambridge; the Geografsko Drustvo na Univerzi and Slovenska Matica, Ljubljana; the Sociedad Cientifica Argentina, Buenos Aires; and the Tokyo Geographical Society, Tokyo. Among the publications received were 4,787 dissertations. These came from the Academy of Freiberg, the universities of Basel, Berlin, Bern, Bonn, Breslau, Budapest, Erlangen, Freiburg, Giessen, Greifswald, Halle, Heidelberg, Helsingfors, Jena, Johns Hopkins, Kiel, Königsberg, Köln, Lund, Marburg, Pennsylvania, Rostock, Tübingen, Utrecht, and Zürich; and technical schools at Berlin, Braunschweig, Delft, Dresden, Karlsruhe, and Zürich. The number of letters written was 2,135. The library arranged for 264 new exchanges—26 more than the year before—and obtained 6,728 publications—an increase of 2,614 over 1934—especially requested by the various libraries of the Institution. Many of these items, however, it should be explained, were found among the Smithsonian duplicates.

GIFTS

As usual, there were many gifts. Prominent among them was a copy of the Yellow Book of Lecan, edited by Robert Atkinson, from the Royal Irish Academy. Others were Corpus Doctrinae Christianae (1570), by Philippum Melanthonem, from Mrs. Charles D. Walcott; Letters of Sir Thomas Bodley to Thomas James, First Keeper of the Bodleian Library, edited by G. W. Wheeler, from the librarian of the Bodleian; Catalogue of the Sanskrit and Prakrit Manuscripts in the Library of the India Office, volume 2, Brahmanical and Jaina Manuscripts (parts 1–2), by Arthur B. Keith, from the Secretary of State for India in Council; A Glossary of the Construction, Decoration, and Use of Arms and Armor, by George Cameron Stone, from the author; Official Records of the Union and Confederate Navies in the War of the Rebellion, in 31 volumes, from the Woman's College Library, Duke University; The Flora of the Niagara Frontier Region, by Charles A. Zenkert, from the author; the Lichen Flora

of the United States, by Bruce Fink, from the University of Michigan Press; Paintings from the Tomb of Rekh-Mi-Re at Thebes, by Norman de Garis Davies, from the Metropolitan Museum of Art; The Moths of South Africa, volume 2, by A. J. T. Janse, from the author; Wild Birds at Home, and The American Eagle, by Francis H. Herrick, from the author; Moss Flora of North America North of Mexico, volume 3, part 4, by A. J. Grout, from the author; Ferns of the Northwest, by Theodore C. Frye, from the author; Trees of the Southeastern States, by W. C. Coker and H. R. Totten, from W. C. Coker; Emile Berliner, Maker of the Microphone, by Frederic William Wile, from Mrs. Emile Berliner; Some Japanese Balloon Prints, by Bella C. Landauer, from the author; Problems of Petroleum Geology, edited by W. E. Wrather and F. H. Lahee, from the American Association of Petroleum Geologists; Index to Jordan's "Genera of Fishes", volumes 1–4, by Hugh M. Smith, and Post-Card Pictures of Siamese Fishes, by Luang Masya Chitrakaru, from Hugh M. Smith; the Cyclist (London), 25 volumes (1879–1903), from A. E. Schaaf; Columbia Catalogues (1878–1911), by the Pope Manufacturing Co., from E. H. Broadwell (through A. E. Schaaf); Narrative of the U. S. Exploring Expedition, during the years 1838, 1839, 1840, 1841, 1842, volume 6 (atlas), by Commander Charles Wilkes, from Mrs. Isabel Brackenridge Hendry; Liberia Rediscovered, by James C. Young, from Harvey S. Firestone; Contributions to Electricity and Magnetism (extracted from the Transactions of the American Philosophical Society, 1839, 1841), by Joseph Henry, from Riley D. Moore; Researches in Cancer: Part 1, 1896–1921, 1922–1932, by C. W. G. Rohrer, from the author; John Adams's Book, compiled by Henry Adams, from the Boston Athenaeum; Simplified Ballistics for Sportsmen, by Harry F. Geist, from the author; Air Conditioning, by E. W. Riesbeck, from the Goodheart-Willcox Co., Inc.

Many publications were received from Mrs. Charles D. Walcott, and 22 volumes of a miscellaneous character from Mrs. George Cabot Lodge. Other gifts included 1,221 publications from the Geophysical Laboratory, 657 from the American Association for the Advancement of Science, several hundred from the Library of Congress, and a number from the Department of State, Department of Commerce, Pan American Union, American Association of Museums, and Anthropological Society, Biological Society, and Helminthological Society of Washington. The largest gift, however, came from the International Catalogue of Scientific Literature, which late in the year turned over to the library about 7,000 publications, chiefly scientific serials, embracing more than 100 titles and not a few long runs. These will be of great value to the library, especially as they

contain many items that are lacking in its sets. Gifts also came from Secretary Abbot, Assistant Secretary Wetmore, and the following other members and associates of the scientific staff: Dr. Paul Bartsch, Dr. R. S. Bassler, Dr. A. G. Böving, August Busck, A. H. Clark, H. B. Collins, W. L. Corbin, F. E. Fowle, Dr. Herbert Friedmann, L. C. Gunnell, Dr. Walter Hough, Dr. Aleš Hrdlička, Neil M. Judd, Dr. Remington Kellogg, Leon Kelso, Dr. E. G. Kirk, Dr. W. C. Mansfield, Dr. W. R. Maxon, G. S. Miller, Jr., Dr. G. S. Myers, A. J. Olmsted, R. G. Paine, Dr. Mary J. Rathbun, and Dr. Waldo Schmitt.

SMITHSONIAN DEPOSIT

The Smithsonian deposit is the main library of the Institution. The collection was kept at the Smithsonian until 1866 when, under a special act of Congress, it was deposited in the Library of Congress, where it has steadily grown, by regular additions from the Institution, from 40,000 volumes, pamphlets, and charts to 540,000. It is distributed among the various divisions of the Library according to the nature of the material, but, as the deposit is largely scientific and technical in character and abounds in the reports, proceedings, and transactions of the learned institutions and societies of the world and in periodicals, both American and foreign, it is shelved for the most part in the Smithsonian and Periodical Divisions. It is the great central collection on which the other libraries of the Institution rely almost daily for necessary publications, many of which can be obtained nowhere else in Washington and some in few other places in America.

To the deposit the Smithsonian library added during the fiscal year just closed 16,500 items, consisting of 2,639 volumes, 9,148 parts of volumes, 3,128 pamphlets, and 1,585 maps and charts. As in former years, several thousand statistical documents that the library received from foreign governments were forwarded, mainly unopened, to the Division of Documents in the Library of Congress.

NATIONAL MUSEUM LIBRARY

Next in importance to the deposit, among the libraries of the Smithsonian Institution, is the library of the United States National Museum. At the close of the year it numbered 88,377 volumes and 112,693 pamphlets, chiefly on natural history and technology. The additions were 11,321 publications, or 1,639 volumes, 8,697 parts of volumes, 980 pamphlets, and 5 charts. The staff sent 101 volumes to the bindery, recorded 8,709 periodicals, cataloged 2,592 publications, and added 21,896 cards to the main catalogs and shelf lists.

They filed 469 cards of the Wistar Institute and 3,774 of the Concilium Bibliographicum, besides sorting 8,871 of the latter for the subject files of the curators. They assigned to the sectional libraries 4,233 current publications—as well as 6,512 reprints that had accumulated over a period of years—and lent to the scientific staff 9,636, of which 2,489 were borrowed from the Library of Congress, especially the Smithsonian deposit, and 442 from other libraries, including 15 from outside of Washington. They made 436 loans to other libraries—an increase of 326 over the year before. They also assisted the libraries of the Bureau of American Ethnology, National Gallery of Art, and National Zoological Park, and advanced materially the work of reorganizing the general collection on technology and the special collections on administration and engineering in the old Museum. The requests for reference and bibliographical service were more numerous than usual and frequently required hours and even days of research not only in the Museum library but in the Library of Congress and elsewhere.

The sectional libraries, which number 35, were not changed during the year. They are as follows:

Administration
Administrative assistant's office
Agricultural history
Anthropology
Archeology
Biology
Birds
Botany
Echinoderms
Editor's office
Engineering
Ethnology
Fishes
Foods
Geology
Graphic Arts
History
Insects
Invertebrate paleontology
Mammals
Marine invertebrates
Medicine
Minerals
Mollusks
Organic chemistry
Paleobotany
Photography
Physical anthropology
Property clerk's office
Reptiles and batrachians
Superintendent's office
Taxidermy
Textiles
Vertebrate paleontology
Wood technology

OFFICE LIBRARY

The Smithsonian office library is shelved partly in or near the offices of the administrative staff and in the main reference and exhibition rooms of the Institution, and partly in the library of the old Museum. It numbers approximately 30,000 items and comprises, in addition to an extensive collection of works of general reference and publications of learned institutions and societies, a small rare-book collection, several important special collections on history and the natural sciences, and many books and periodicals

of less scholarly interest designed primarily for the home hours of the employees.

The additions to the library in 1935 were 240 volumes, 773 parts of volumes, and 22 pamphlets. The staff entered 3,448 periodicals, prepared and filed 1,683 catalog cards, classified 3,665 aeronautical clippings and mounted 1,415, made 146 cards for the aeronautical file, received 2,252 visitors, and loaned 2,954 publications. These statistics include some for the technological library of the National Museum, inasmuch as both collections are served, for the most part, by the same library attendants.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology concerns itself chiefly with the primitive peoples of the Western Hemisphere, notably the North American Indians. It consists of 31,101 volumes and 17,189 pamphlets, besides important manuscripts, vocabularies, and photographs. It was increased during the year by 400 volumes and 94 pamphlets. The staff cataloged 788 publications, recorded 3,125 periodicals, added 3,865 cards to the catalog, made 1,069 loans, and rendered even more than usual reference and bibliographical service to the scientists of the Bureau and other investigators. The regular attendants had the assistance at different times during the year of two trained employees from other libraries of the Institution, who advanced materially the preparation of cards for the Bureau's catalog, as well as for the union catalog of the Smithsonian, and began the checking of the sets of society publications, with a view to obtaining needed numbers by exchange while they are still available; 81 of these were found in the duplicate collection of the Institution.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory deals largely with meteorology and astrophysics. Its accessions of 57 volumes, 1,033 parts of volumes, and 75 pamphlets increased the collection during the fiscal year to 4,624 volumes and 3,903 pamphlets. The number of cards added to the catalog was 1,633. The loans were 127.

RADIATION AND ORGANISMS LIBRARY

The library of radiation and organisms, the youngest and smallest unit in the Smithsonian library system, is a collection of 207 volumes, 14 pamphlets, and 6 charts pertaining mainly to the radiation of the sun and its effect on plant and animal life. It was increased in 1935 by 6 volumes, 224 parts of volumes, and 2 pamphlets.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library is the Institution's well-known collection of aeronautical publications, which was brought together in the first instance by Samuel Pierpont Langley, and later increased by gifts from Alexander Graham Bell, Octave Chanute, and James Means, and since by regular additions from the Smithsonian. In 1930 most of the library was sent as a special deposit to the Library of Congress, where, under its own name and bookplate, it supplements in important respects for research purposes the Government's chief collection. The library has 2,009 volumes, 1,179 pamphlets, and 29 charts. Among its items are many early aeronautical magazines, as well as manuscripts, photographs, and newspaper clippings. The accessions in 1935 were 31 volumes, 538 parts of volumes, and 51 pamphlets. In response to special requests from the division of aeronautics in the Library of Congress, the Smithsonian library obtained 78 publications needed in the Langley sets.

NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art has no regular trained attendant. The staff of the Smithsonian and Museum libraries, assisted by several F. E. R. A. workers, however, were able to keep up most of the current work of the library to continue, in a measure, the task of bringing together and cataloging its collections, which was begun several years before. The accessions were 316 volumes and 306 pamphlets, which increased the library to 2,447 volumes and 2,030 pamphlets. The staff entered 1,621 periodicals, cataloged 672 publications, added 2,341 cards to the catalog and shelf list, prepared 543 cards for other files, and labeled 668 books. Of the accessions, 142 were obtained by special exchange correspondence. Toward the close of the year, 1,935 publications were transferred to the library from the section of administration in the National Museum.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art received further expert attention in 1935. Consequently by the close of the fiscal year the dictionary catalog, which had been begun several years before, was finished to date, except for a number of the Chinese and Japanese items. The staff cataloged 225 publications, prepared 3,013 cards for the library files, as well as 658 for the union catalog at the Smithsonian Institution, and sent 19 volumes to the bindery. The main collection, which numbers 5,297 volumes and 3,521 pamphlets, was increased by 326 volumes, 170 parts of volumes, and 56 pamphlets; the field collection by 369 volumes, 627 parts of volumes, 103

pamphlets, and 69 maps. The latter, which had been for some years in China, where until recently the Freer was carrying on important archeological investigations, was brought back to Washington and deposited in the Gallery. During its sojourn abroad it grew considerably and now numbers 1,920 volumes, 640 pamphlets, and 69 maps. Together the two collections, which relate almost entirely to the chief interests of the Freer—namely, the art and culture of the Far East, India, Persia, and the nearer East, and the activities of certain American painters, notably James McNeill Whistler, many of whose works are owned by the Gallery—contain not a few rare items and supplement to an important degree the collections at the Library of Congress, particularly those in the manuscript, fine arts, and oriental divisions. The treasures of the library are, of course, the "Washington Manuscripts" of the Bible, dating from the fourth and fifth centuries.

NATIONAL ZOOLOGICAL PARK LIBRARY

The library of the National Zoological Park comprises 1,412 volumes and 1,962 pamphlets chiefly on the care, study, and exhibition of wild animals. The accessions in 1935 were 82 volumes, 107 parts of volumes, and 102 pamphlets. Besides these, 2,394 publications of special interest to the scientists of the Park were selected late in the year from the duplicates at the Smithsonian Institution and the Library of Congress and will in due time be made part of the collection. The number of cards added to the catalog was 540. Two trained assistants were employed for brief periods during the year.

SUMMARY OF ACCESSIONS

The accessions for the fiscal year may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	57	75	132
Bureau of American Ethnology	400	94	494
Freer Gallery of Art	695	228	923
Langley Aeronautical	31	51	82
National Gallery of Art	316	306	622
National Zoological Park	82	102	184
Radiation and Organisms	6	2	8
Smithsonian Deposit, Library of Congress	2,639	4,713	7,352
Smithsonian Office	240	22	262
United States National Museum	1,639	985	2,624
Total	6,105	6,578	12,683

These accessions, together with the additions represented by the Freer field collection, incident to its being brought to Washington and given a place in the library of the Gallery, increased the ap-

proximate number of publications in the library system of the Institution to the following:

Volumes	605, 117
Pamphlets	215, 042
Charts	28, 358
Total	848, 517

This total does not, of course, include the many thousands of volumes that are not yet completed, bound, or cataloged.

SPECIAL ACTIVITIES

Besides meeting the current demands, the staff continued several important undertakings left over from the C. W. A. days, and engaged in two or three new ones, related to the general work of reorganizing the Smithsonian library system that was begun some years ago. In carrying out these special projects, it was assisted by a number of F. E. R. A. workers, who were assigned to the Institution for different periods during the year.

Among the projects, two were outstanding. The work of sorting and arranging the foreign scientific and technical duplicates in the west stacks of the Smithsonian Building and labeling the shelves of the entire collection, both American and foreign, was carried toward completion. One result of this undertaking was that, of the 6,728 publications especially requested during the year by the libraries of the Institution, about 40 percent were found in this collection. It is expected that as the checking of the standard sets in the libraries goes on, thousands more of the items lacking will be available here. Another result was that it was possible for the Smithsonian library to cooperate, to the extent of more than 1,100 numbers, with the American Association for the Advancement of Science in its endeavor to form a set of the publication *Science* for its office use—a slight return for the many generous gifts that the Association has made to the library in recent years; it was also possible for the library to present 283 numbers of the Journal of the Washington Academy of Sciences, as suggested by the Library of Congress, to the Akademiia Nauk, Leningrad, to help that institution fill out its set. Still another result was that substantial runs of various important serials were assembled, to be filed later in the reserve section of the library for use either to reinforce the main sets or to replace them when they are worn out.

The second outstanding project was the sorting and reassignment of the contents of the sectional libraries of administration and engineering. The material no longer needed by the officials concerned was disposed of in various ways. The work of taking inventory and arranging the items to be retained in the sections was also undertaken.

Another activity of considerable importance was the careful examination of a large accumulation of maps—the second to be treated in this manner the last few years—with the result that about 500 were chosen for the Museum library and 1,576 sent to the Smithsonian deposit, where they would be of service in completing the files of the Library of Congress and still be available to the scientists of the Institution as well as to investigators outside.

Among other activities a few should be mentioned. Special sendings of duplicates were made to Harvard, Yale, Princeton, Brown, the University of Pennsylvania, Vanderbilt, and the Marine Biological Laboratory at Woods Hole, and 150 or more publications, both old and new, which were needed by the National Museum and the National Gallery of Art, were obtained in exchange; about 20,000 publications, many of them Government documents, not required by the library, were sent back to the issuing bureaus or transferred to various Federal libraries; 2,750 returned publications of the Smithsonian and its branches were checked and 351 found that were needed in the library sets; the dictionary index of Smithsonian publications was kept up to date, and considerable progress was made on the index of exchange relations; the union catalog was also advanced, as the following table will show:

Volumes cataloged	4,239
Pamphlets cataloged	2,514
Charts cataloged	14
New serial entries made	121
Typed cards added to catalog and shelf list	5,866
Library of Congress cards added to catalog and shelf list	16,085

CONCLUSION

The year, then, was one of noteworthy progress, despite the regrettable fact that it was again found necessary, owing to economic conditions, to curtail the funds, almost to the vanishing point, customarily allotted to the library for binding and for the employment of extra trained assistants.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1935:

The Institution published during the year 32 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report and pamphlet copies of the 20 articles contained in the report appendix, and 1 special publication. The United States National Museum issued 1 annual report and 7 separates from the Proceedings. The Bureau of American Ethnology issued 1 annual report. The Freer Gallery of Art issued 1 publication in the series of Oriental Studies.

Of the publications there were distributed 124,186 copies, which included 48 volumes and separates of the Smithsonian Contributions to Knowledge, 64,218 volumes and separates of the Smithsonian Miscellaneous Collections, 15,799 volumes and separates of the Smithsonian Annual Reports, 3,800 Smithsonian special publications, 26,592 volumes and separates of the National Museum publications, 11,955 publications of the Bureau of American Ethnology, 55 publications of the National Gallery of Art, 1,281 publications of the Freer Gallery of Art, 40 Annals of the Astrophysical Observatory, 22 reports of the Harriman Alaska Expedition, and 376 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 89, there was issued the title page and table of contents; volume 91, 5 papers; volume 92, 13 papers and title page and table of contents; volume 93, 9 papers; and volume 94, 5 papers, making 32 papers in all, as follows:

VOLUME 89

Title page and table of contents. (Publ. 3331.)

VOLUME 91

Reports on the collections obtained by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep.

No. 16. New marine mollusks, by Lois F. Corea. 9 pp., 3 pls. (Publ. 3258.) September 18, 1934.

No. 17. New sponges from the Puerto Rican Deep, by M. W. de Laubenfels. 28 pp. (Publ. 3283.) December 24, 1934.

No. 18. New monogenetic trematodes from marine fishes, by Emmett W. Price. 3 pp., 1 pl. (Publ. 3286.) November 8, 1934.

No. 19. New parasitic copepods, by Charles Branch Wilson. 9 pp., 3 pls. (Publ. 3298.) April 8, 1935.

No. 20. *Bollmania litura*, a new species of goby, by Isaac Ginsburg. 3 pp., 1 pl. (Publ. 3299.) April 10, 1935.

VOLUME 92

No. 1. The hypotrochanteric fossa of the femur, by Aleš Hrdlička. 49 pp., 14 pls. (Publ. 3250.) August 4, 1934.

No. 2. New fresh-water mollusks from northern Asia, by Alan Mozley. 7 pp., 1 pl. (Publ. 3253.) August 8, 1934.

No. 3. Lethal response of the alga *Chlorella vulgaris* to ultraviolet rays, by Florence E. Meier. 12 pp., 3 pls. (Publ. 3254.) August 6, 1934.

No. 5. Colonial formation of unicellular algae under various light conditions, by Florence E. Meier. 14 pp., 3 pls. (Publ. 3256.) October 8, 1934.

No. 6. Effects of intensities and wave lengths of light on unicellular green algae, by Florence E. Meier. 27 pp., 3 pls. (Publ. 3257.) October 11, 1934.

No. 7. Herpetological collections from the West Indies made by Dr. Paul Bartsch under the Walter Rathbone Bacon Scholarship, 1928–1930, by Doris M. Cochran. 48 pp. (Publ. 3259.) October 15, 1934.

No. 8. Samuel Pierpont Langley, by C. G. Abbot. 57 pp., 6 pls. (Publ. 3281.) August 22, 1934.

No. 9. The skeletal musculature of the blue crab, *Callinectes sapidus* Rathbun, by Doris M. Cochran. 76 pp., 30 figs. (Publ. 3282.) January 22, 1935.

No. 10. Recent discoveries of Cambrian beds in the northwestern United States, by Charles Elmer Resser. 10 pp. (Publ. 3284.) November 6, 1934.

No. 11. Phototropic sensitivity in relation to wave length, by Earl S. Johnston. 17 pp., 2 pls., 4 figs. (Publ. 3285.) December 6, 1934.

No. 12. Remarkable lightning photographs, by C. G. Abbot. 3 pp., 1 pl. (Publ. 3287.) November 2, 1934.

No. 13. The standard scale of solar radiation, by C. G. Abbot and L. B. Aldrich. 3 pp. (Publ. 3288.) November 2, 1934.

No. 14. Archeological investigations in the Bay Islands, Spanish Honduras, by William Duncan Strong. 176 pp., 33 pls., 38 figs. (Publ. 3290.) February 12, 1935.

Title page and table of contents. (Publ. 3332.)

VOLUME 93

No. 1. The effect of ultraviolet radiation on the ova of the ascarid roundworms *Toxocara canis* and *Toxascaris leonina*, by W. H. Wright and E. D. McAlister. 13 pp. (Publ. 3291.) December 26, 1934.

No. 2. Mud shrimps of the Atlantic coast of North America, by Waldo L. Schmitt. 21 pp., 4 pls. (Publ. 3292.) February 15, 1935.

No. 3. New earthworms from China, with notes on the synonymy of some Chinese species of Drawina and Pheretima, by G. E. Gates. 19 pp., 15 figs. (Publ. 3293.) February 27, 1935.

No. 4. Pioneer wind tunnels, by N. H. Randers-Pehrson. 20 pp., 4 pls. (Publ. 3294.) January 19, 1935.

No. 5. Nomenclature of some Cambrian trilobites, by Charles Elmer Resser. 46 pp. (Publ. 3295.) February 14, 1935.

No. 6. Ear exostoses, by Aleš Hrdlička. 98 pp., 5 pls. (Publ. 3296.) May 14, 1935.

No. 7. The Christiansen light filter: Its advantages and limitations, by E. D. McAlister. 12 pp., 2 pls., 4 figs. (Publ. 3297.) April 2, 1935.

No. 8. The classification of the Edrioasteroidea, by R. S. Bassler. 11 pp., 1 pl. (Publ. 3301.) April 4, 1935.

No. 9. New species of Tertiary Cheilostome Bryozoa from Victoria, Australia, by Ferdinand Canu and Ray S. Bassler. 54 pp., 9 pls. (Publ. 3302.) April 26, 1935.

VOLUME 94

No. 1. The darker side of dawn, by Ananda K. Coomaraswamy. 18 pp. (Publ. 3304.) April 17, 1935.

No. 2. Concerning the Badianus manuscript, an Aztec herbal, "Codex Barberini, Latin 241" (Vatican Library), by Emily Wolcott Emmaert. 14 pp., 4 pls. (Publ. 3329.) May 18, 1935.

No. 3. Thomas Lincoln Casey and the Casey collection of Coleoptera, by L. L. Buchanan. 15 pp., 1 pl. (Publ. 3330.) June 8, 1935.

No. 4. A Folsom complex: Preliminary report on investigations at the Lindenmeier site in northern Colorado, by Frank H. H. Roberts, Jr. 35 pp., 16 pls., 3 figs. (Publ. 3333.) June 20, 1935.

No. 5. Wave lengths of radiation in the visible spectrum inhibiting the germination of light-sensitive lettuce seed, by Lewis H. Flint and E. D. McAlister, 11 pp., 5 figs. (Publ. 3334.) June 24, 1935.

SMITHSONIAN ANNUAL REPORTS

Report for 1933.—The complete volume of the Annual Report of the Board of Regents for 1933 was received from the Public Printer in June 1935.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1933. xiv+468 pp., 56 pls., 67 text figs. (Publ. 3260.)

The appendix contained the following papers:

How the sun warms the earth, by C. G. Abbot.

Gravitation in the solar system, by Ernest W. Brown.

The structure and rotation of the galaxy, by J. S. Plaskett.

The contents of interstellar space, by C. G. Abbot.

Some points in the philosophy of physics: Time, evolution, and creation, by E. A. Milne, F. R. S.

Stands science where she did? by Ivor Thomas.

High voltage, by Karl T. Compton.

The battle of the alchemists, by Karl T. Compton.

Romance or science? by Paul R. Heyl.

Origin of folded mountains, by W. F. Prouty.

Meteorite craters as topographical features on the earth's surface, by Dr. L. J. Spencer, F. R. S.

A geologist's paradise, by R. S. Bassler.

Nature's own seaplanes, by Carl L. Hubbs.

The microscopic plant and animal world in ultraviolet light, by Florence E. Meier.

The history of an insect's stomach, by R. E. Snodgrass.

Ticks and the role they play in the transmission of diseases, by F. C. Bishopp.

The forehead, by Aleš Hrdlička.

The historical significance of Tepe Gawra, by E. S. Speiser.

Indian manuscripts of southern Mexico, by Herbert J. Spinden.

Archeology of the Bering Sea region, by Henry B. Collins, Jr.

Report for 1934.—The report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and will form part of the annual report of the Board of Regents to Congress, was issued in December 1934.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ending June 30, 1934. 78 pp., 1 pl. (Publ. 3289.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Explorations and Field-Work of the Smithsonian Institution in 1934. 88 pp., 84 pls. (Publ. 3300.) April 22, 1935.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report and 7 separates from the Proceedings, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1934. 109 pp.

PROCEEDINGS: VOLUME 83

No. 2972. *Corynecrinus*, a new Devonian crinoid genus. By Edwin Kirk. Pp. 1–7, pl. 1.

No. 2973. American muscoid flies of the genera *Ceratomyiella* and *Paradidyma*. By H. J. Reinhard. Pp. 9–43.

No. 2974. Revision of the American two-winged flies belonging to the genus *Cuphocera*. By H. J. Reinhard. Pp. 45–70.

No. 2975. Some fossil corals from the West Indies. By John W. Wells. Pp. 71–110, pls. 2–5.

No. 2976. Fossil hares from the late Pliocene of southern Idaho. By C. Lewis Gazin. Pp. 111–121, figs. 1–5.

No. 2977. Parasites of fishes in Galveston Bay. By Asa C. Chandler. Pp. 123–157, pls. 6–12.

No. 2978. On the Reptilia of the Kirtland formation of New Mexico, with descriptions of new species of fossil turtles. By Charles W. Gilmore. Pp. 159–188, figs. 6–17, pls. 13–18.

Beginning with volume 83 of the Proceedings, covers for separate papers were omitted, and pages, figures, and plates were numbered consecutively throughout each volume, instead of each article separately, as has been the practice for many years.

INDEX OF MUSEUM PUBLICATIONS

Under the direction of the Museum editor, work was continued on the index of Museum publications, which has been in progress 2 years. The index is now completed through Bulletin 43 and Proceedings, volume 16. About 30,000 cards were added during the year, making a total of 115,000, exclusive of 79,000 not entered in the master file. The index, in its current form, is available to the curators and others who may have occasion to use it. It is hoped to be able to publish at least some of it by 1946, the Smithsonian Institution Centenary.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year one annual report was issued.

Fifty-first Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1933–1934. 8 pp.

Progress was made on verifying the manuscript index of the Bulletins 1–100 of the Bureau, and the index to the six volumes of Schoolcraft's work entitled "Indian Tribes" was well advanced.

FREER GALLERY OF ART PUBLICATIONS

Oriental Studies, No. 2. A descriptive and illustrated catalogue of miniature paintings of the Jaina Kalpasūtra as executed in the early western Indian style. By W. Norman Brown. 4°. 66 pp., 45 pls. (Publ. 3252.) December 14, 1934.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual report for 1932 was issued during the year. The supplemental volumes to Reports for 1931 and 1932 were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-seventh Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, March 14, 1935.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Reports to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1936, totals $25,500, allotted as follows:

Smithsonian Institution	$12, 250
National Museum	7, 050
Bureau of American Ethnology	2, 000
American Historical Association	4, 200

Respectfully submitted.

W. P. True, *Editor.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1935

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960,8s.6d.; $508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550,000.00
Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of	1,106,803.19

The Institution holds also a number of endowment gifts the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun	$42,596.31
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	53,361.64
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	9,353.50
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	810.18
Canfield Collection fund, for increase and care of the Canfield collection of minerals	40,736.41
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	8,231.31
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	29,993.32
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100,000.00
Special Research fund, gift, in form of real estate	20,946.00
Hughes, Bruce, fund, to found Hughes alcove	16,136.12
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art	20,189.80

Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection	$2,571.54
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000	65,275.28
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis	29,968.99
Roebling fund, for care, improvement, and increase of Roebling collection of minerals	128,537.36
Rollins, Miriam and William, fund, for investigations in physics and chemistry	55,727.40
Springer, Frank, fund, for care, etc., of Springer collection and library	14,883.04
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	11,062.72
Younger, Helen Walcott, fund, held in trust	50,112.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria	810.61
Total endowment for specific purposes other than Freer endowment	701,304.03

The capital funds of the Institution, except the Freer funds, are invested as follows:

Fund	United States Treasury	Consolidated fund	Separate fund	Total
Arthur, James		$42,596.31		$42,596.31
Bacon, Virginia Purdy		53,361.64		53,361.64
Baird, Lucy H.		9,353.50		9,353.50
Barstow, Frederic D.		810.18		810.18
Canfield Collection		40,736.41		40,736.41
Casey, Thomas L.		8,231.31		8,231.31
Chamberlain		29,993.32		29,993.32
Hodgkins (specific)	$100,000			100,000.00
Special Research fund			$20,946.00	20,946.00
Hughes, Bruce		16,136.12		16,136.12
Myer, Catherine W.		20,189.80		20,189.80
Pell, Cornelia Livingston		2,571.54		2,571.54
Poore, Lucy T. and George W.	26,670	38,605.28		65,275.28
Reid, Addison T.	11,000	14,468.99	4,500.00	29,968.99
Roebling Collection		128,537.36		128,537.36
Rollins, Miriam and William		46,227.40	9,500.00	55,727.40
Smithsonian unrestricted funds:				
Special			1,400.00	1,400.00
Avery	14,000	39,660.24		53,660.24
Endowment		162,714.81		162,714.81
Habel	500			500.00
Hachenberg		4,285.33		4,285.33
Hamilton	2,500	429.95		2,929.95
Henry		1,288.14		1,288.14
Hodgkins (general)	116,000	31,942.53		147,942.53
Parent	727,640	1,300.23		728,940.23
Rhees	590	503.86		1,093.86
Sanford	1,100	948.10		2,048.10
Springer			14,883.04	14,883.04
Walcott, Charles D. and Mary Vaux		11,062.72		11,062.72
Younger, Helen Walcott			50,112.50	50,112.50
Zerbee, Frances Brincklé		810.61		810.61
Total	1,000,000	706,765.68	101,341.54	1,808,107.22

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by

Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $4,769,362.53. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$534, 318. 17
Court and grounds maintenance fund	134, 352. 68
Curator fund	543, 728. 40
Residuary legacy	3, 556, 963. 28
	4, 769, 362. 53

SUMMARY

Invested endowment for general purposes	$1, 106, 803. 19
Invested endowment for specific purposes other than Freer endowment	701, 304. 03
Total invested endowment other than Freer endowment	1, 808, 107. 22
Freer invested endowment for specific purposes	4, 769, 362. 53
Total invested endowment for all purposes	6, 577, 469. 75

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum as authorized in the U. S. Revised Statutes, sec. 5591		$1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (18 different groups)	$363, 887. 25	
Stocks (39 different groups)	398, 693. 67	
Real estate first-mortgage notes	41, 746. 00	
Uninvested capital	3, 780. 30	
		808, 107. 22
Total investments other than Freer endowment		1, 808, 107. 22
Investments of Freer endowment (cost or market value at date acquired):		
Bonds (43 different groups)	$2, 240, 386. 62	
Stocks (31 different groups)	2, 156, 825. 38	
Real estate first-mortgage notes	38, 500. 00	
Uninvested capital	333, 650. 53	
		4, 769, 362. 53
Total investments		6, 577, 469. 75

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1934		$250, 118. 80
Receipts:		
Cash income from various sources for general work of the Institution	$66, 558. 01	
Cash gifts expendable for special scientific objects (not to be invested)	49, 096. 04	
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)	62, 933. 04	
Cash capital from sale, call of securities, etc. (to be reinvested)	99, 592. 16	
Total receipts other than Freer endowment		278, 179. 25
Cash receipts from Freer endowment:		
Income from investments, etc	$257, 510. 33	
Cash capital from sale, call of securities, etc. (to be reinvested)	1, 176, 081. 31	
Total receipts from Freer endowment		1, 433, 591. 64
Total		1, 961, 889. 69
Disbursements:		
From funds for general work of the Institution:		
Buildings, care, repairs, and alterations	$2, 361. 88	
Furniture and fixtures	170. 78	
General administration [2]	24, 163. 12	
Library	2, 449. 87	
Publications (comprising preparation, printing, and distribution)	16, 507. 36	
Researches and explorations	17, 929. 34	
International exchanges	4, 864. 63	
		68, 446. 98
From funds for specific use, other than Freer endowment:		
Investments made from gifts, from gain from sale, etc., of securities and from savings on income	$6, 265. 32	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	75, 497. 78	
Reinvestment of cash capital from sale, call of securities, etc	133, 717. 40	
		$215, 480. 50

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] This includes salary of the Secretary and certain others.

Disbursements—Continued.

From Freer endowment:		
Operating expenses of the gallery, salaries, field expenses, etc	$57,908.53	
Purchases of art objects	136,141.19	
Investments made from gain from sale, etc., of securities	278,962.32	
Reinvestment of cash capital from sale, call of securities, etc	626,378.05	
		$1,099,390.09
Cash balance June 30, 1935		578,572.12
Total		1,961,889.69

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, PUBLICATIONS, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:		
Publications	$16,507.36	
Researches and explorations	17,929.34	
		$34,436.70
Expenditures from funds devoted to specific purposes:		
Researches and explorations	42,920.24	
Care, increase, and study of special collections	12,366.86	
Publications	7,323.05	
		62,610.15
Total		97,046.85

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $883.47.

The Institution gratefully acknowledges gifts or bequests from the following:

Mr. W. N. Beach, for purchase of certain specimens of birds.

Mrs. Laura Welsh Casey, for further contributions to Thomas Lincoln Casey fund, for investigations in Coleoptera.

Mr. Eldridge R. Johnson, further contributions for expenses in connection with deep-sea and other oceanographic explorations.

Research Corporation, further contributions for researches in radiation.

Mr. John A. Roebling, further contributions for researches in radiation.

Mrs. Mary Vaux Walcott, contribution for the publication of special volume of North American Wild Flowers and purchase of certain Alaskan Archeological specimens.

From an anonymous friend, for further investigations in Old World Archeology.

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1935.

Salaries and expenses		$36,475.40
International exchanges		41,188.17
American Ethnology		56,502.62
Astrophysical Observatory		29,774.21
National Museum:		
Maintenance and operation	$137,093.72	
Preservation of collections	573,407.94	
		710,501.66
National Gallery of Art		33,087.44
Printing and binding		17,500.00
For printing and binding two volumes of that portion of the Annual Report of the American Historical Association devoted to the bibliography, "Writings on American History"		8,000.00
National Zoological Park		199,043.63
		1,132,073.13

There was also an allotment of $5,600 made for participation by the Smithsonian Institution in the California Pacific International Exposition.

The report of the audit of the Smithsonian private funds is printed below:

AUGUST 19, 1935.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1935, and certify the balance of cash on hand June 30, 1935, to be $580,472.12 [which includes $1,900 held in cash at the Institution].

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1935, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1935.

Respectfully submitted.

William L. Yaeger & Co.,
William L. Yaeger,
Certified Public Accountant.

Respectfully submitted.

Frederic A. Delano,
R. Walton Moore,
John C. Merriam,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1935

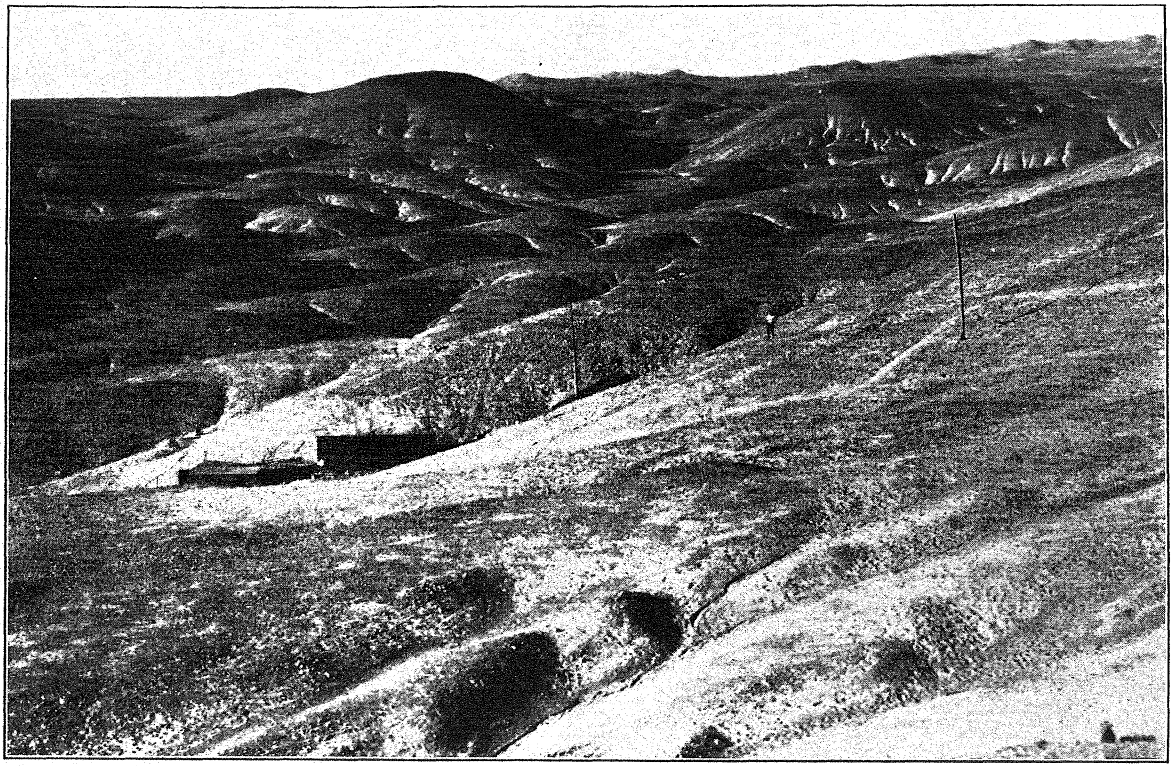
ADVERTISEMENT

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1935.



SURROUNDINGS OF SMITHSONIAN SOLAR OBSERVING STATION AT MONTEZUMA, CHILE.

The observatory is at the top of the peak on the right, outside the photograph.

WEATHER GOVERNED BY CHANGES IN THE SUN'S RADIATION

By C. G. Abbot
Secretary, Smithsonian Institution

[With 1 plate]

It is now nearly 20 years since the Smithsonian Institution began to observe daily, whenever possible, the intensity of the rays of the sun. These studies have been continued first at the city of Calama, in northern Chile, and since 1920 by the generous aid of John A. Roebling, at Montezuma, a mountain 9,000 feet high about 12 miles south of Calama. Plate 1 shows the barren location at Montezuma. Neither bird nor beast, shrub nor tree, grass nor desert plant, insect nor creeping thing (except the ubiquitous house fly) can exist in this waterless desert. The great naturalist Darwin, in his journal entitled "The Voyage of the Beagle", relates that he rode all day in that Desert of Atacama seeing no live thing except some flies feasting on the body of a dead mule. In such a place our observers devotedly measure and compute about 9 hours each day for a 3-year period before being relieved. Water and provisions they must haul by auto from Calama, 12 miles distant.

Two other Smithsonian solar stations are in occupation. One is in a still more desolate and remote location, Mount St. Katherine, 8,500 feet in elevation, 10 miles from the ancient monastery of St. Katherine on Mount Sinai in Egypt. The other, at 7,500 feet elevation, overlooks the Mojave Desert in California. But here trees, water and easy accessibility relieve the lonely plight of the observers.

At these desert mountain stations, where rain seldom falls, it is possible to observe the sun through cloudless sky on upward of 75 percent of all days. The great majority of dwellers on low ground and in the cities have never in their lives seen such blue, cloudless, and limpid sky as these stations afford. They have been chosen after much research, travel, and actual testing. For to measure the rays of the sun in such a way as to be able to eliminate the losses its beam suffers in passing through our atmosphere, so as to determine the real emissive power of the sun, is a task of extreme difficulty, even under ideal sky conditions, and is impossible otherwise.

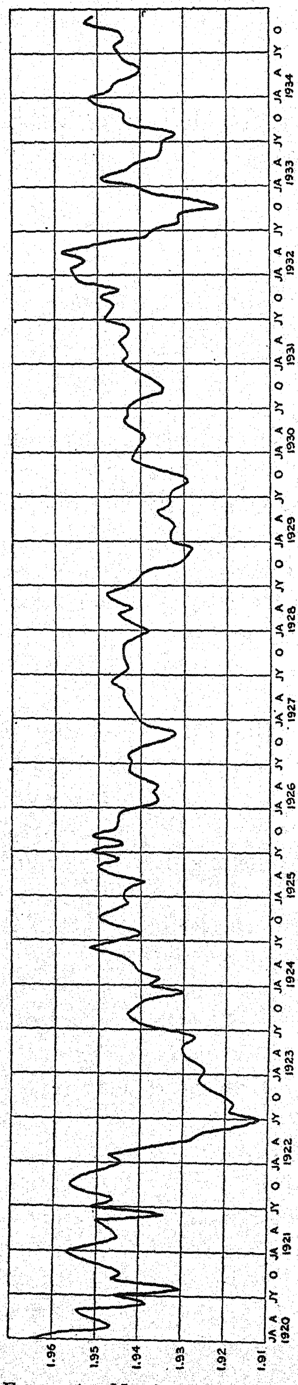


FIGURE 1.—March of solar variation, 1920–34.

It is not sufficient to measure the solar rays as a whole. They must be resolved into their spectrum in order to evaluate the losses from water vapor, ozone, and other atmospheric absorbents. The spectrum includes not only the seven familiar colors as described by Sir Isaac Newton, but beyond the violet and beyond the red lie long regions, dark to our eyes, but containing a substantial proportion of the energy of the solar beam. To measure all these rays we use the bolometer, invented by Langley. It is an electrical thermometer so sensitive that a millionth of a degree of heat is easily measured by it.

Observations with the bolometer and other instruments occupy the observers for about 3 hours each morning. From 5 to 8 hours of computing follow before they are ready to send their telegram to Washington, announcing their result for the intensity of the solar rays on that day. The measures are expressed in heat units called calories. The calorie is the amount of heat required to warm a gram of water 1° C. Those more familiar with English units may recall that there are about 28 grams in 1 ounce, and 1° C.= 1°.8 F. The intensity of solar radiation as it is in free space just outside our atmosphere at mean solar distance is found to fluctuate about a mean value of 1.94 calories per square centimeter per minute.

Having now accumulated for more than 15 years measures of the solar emission (which has long been called the "solar constant", though as we shall see it is variable), we have examined its variations to detect periodicities. This search has now revealed 12 periodicities by the combination of which the sun's heat available to warm the earth fluctuates through several percent. Figure 1 illustrates this fluctuation since 1920, as far as it appears

in the 10-day mean values. There are, indeed, quicker solar variations which run their courses in a few days, and these are believed to have important effects on weather, but the study of them must be deferred until steps now being taken somewhat increase the accuracy of our daily observations. In mean values covering 10 days, or better still 1 month, the daily errors, some being plus, some minus, are largely smoothed away.

Figure 2 shows the monthly mean solar-constant values since 1920 analyzed to yield the 12 periodicities above referred to. In making the analysis the data are treated in several separate parcels for all the periodicities of 25 months and less, so as to see if the earlier and later years agree in presenting similarly the periodicity in question. In illustration, I call attention to the periodicity of 11 months, for which the results of three partial analyses of 5 years each are first shown. At the bottom of that series a heavier line gives the general mean for 15 years. A fair agreement between the three 5-year intervals is apparent. However, as all the periodicities, and the accidental errors besides, are confused in the original data, it is not possible to separate perfectly and determine accurately the individual periodicities as well as one would like to do. Especially for the longer periodicities, of 34 months and over, the determinations of the curves are imperfect because in 15 years there are so few repetitions of them.

Curve B is the summation of the 12 periodicities indicated by the heavy lines at the bottom of figure 2. When compared with the original curve of observation A, it is apparent that a very good fit has been obtained. Not only major changes such as that of 1922, but minor details in the curve of observation A are closely repeated in the synthetic curve B. In fact, the average departure between curves A and B over the 180 months covered by curve A, figure 2, is less than one-fifth of 1 percent. This is really a surprisingly good result and lies, indeed, within the accidental error of the observations.

It seems apparent, therefore, that the emission of the sun varies, and that its variation is the complex result of the simultaneous existence of at least a dozen periodic terms. But what adds decidedly to the interest of this conclusion is a fact that happened to be noticed after many of the periodicities had been found. It is this: They are all approximately integral submultiples, or, as we should say in arithmetic, aliquot parts of 23 years. For 23 years is 276 months, which divided by the numbers 1, 3, 4, 6, 7, 8, 11, 13, 25, 28, 34, and 39, gives, respectively: 23 years, 92, 68, 46, $39\frac{3}{7}$, 34, $25\frac{1}{11}$, $21\frac{3}{13}$, $11\frac{1}{25}$, $9\frac{7}{8}$, $8\frac{2}{17}$, and $7\frac{1}{13}$ months.

If 274 months rather than 276 had been chosen as the least common denominator, the series of numbers just given would certainly have

fitted within the error of determination with the lengths of the periods given in figure 2. It is not to be supposed that the period of the fundamental solar fluctuation, whatever its cause, has any exact relationship to the year or the month, but it is probably a period of time lying somewhere between 272 and 276 months.

It is interesting to remember that nearly 30 years ago Dr. George E. Hale discovered magnetism in sun spots. It has been observed ever since. The curious fact has been observed that the magnetism

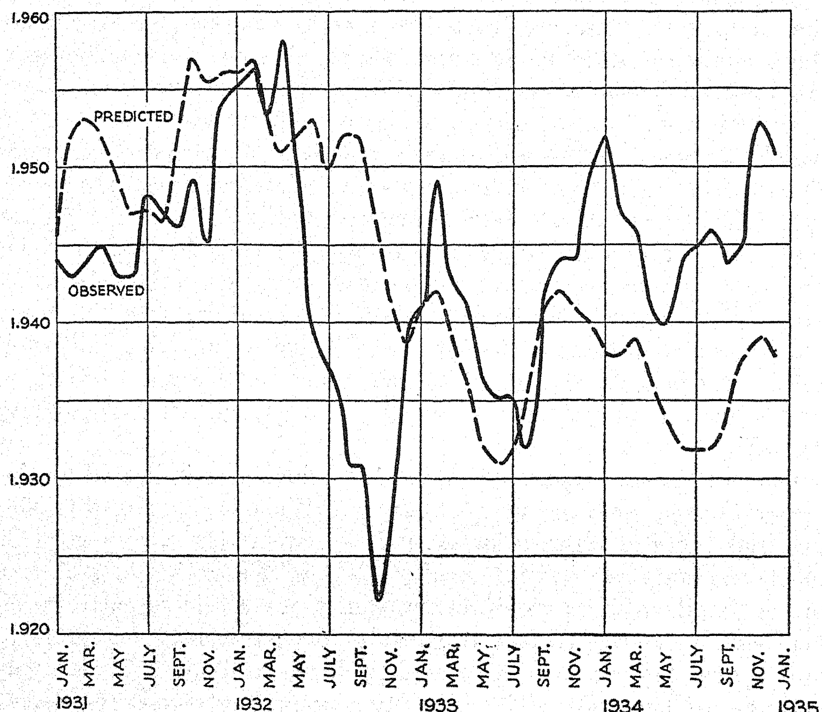


FIGURE 3.—Predicted and observed solar variation. The maxima and minima occur in the two curves at nearly identical phases. The observed curve may be faulty in 1932 owing to the Chilean volcanic eruption. The separation of the curves toward the end is due to a 23-year periodicity not taken account of.

of sun spots reverses its sign approximately each 11½ years, so that approximately 23 years are required to carry the sun through a complete magnetic cycle. Also, it has been well known for over a century that sun spots fluctuate in prevalence with a period which is irregular, but averages about 11⅙ years. The irregularity of the sun-spot cycle is, however, large, ranging from 8 to 16 years, so that the discrepancy between the usually preferred period, 11⅙ years, and the half of 23 years is not perhaps significant.

As we well know, a violin string, for instance the A string above middle C of the scale, vibrates in a fundamental and many har-

monics at the same time. The harmonics are, indeed, the sources of the distinguishing quality of the violin sound. The sun's radiation seems to behave similarly. But it is not clear why the sun, a great ball of compressed hot gas, should vibrate in a fundamental and numerous harmonics, as a violin string or a bell does. Though the cause is obscure, it is believed that the fact is demonstrated. So confident of it was I, that in 1930, and again in 1932, though not then in possession of analyses of the solar variation as satisfactory as figure 2, I ventured to forecast publicly for 2 years in advance the solar variation. Figure 3 shows these forecasts and the event. It will be seen that maxima and minima fall about at the times expected, but that the fit is by no means so close as in figure 2. This was due to the lack, at the time of those predictions, of the more recent discovery of the terms of 34, 39½, 92, and 276 months.

Everyone is aware that the weather is in the main controlled by the earth's relation to the sun. Our alternate exposure to the sun and to dark space by the daily rotation of the earth produces day and night, with their warming and cooling. Revolution about the sun in a plane 23½° out of the plane of the Equator causes the sun to appear far south in January and far north in July, with attendant cooling and warming of the Northern Hemisphere. The ellipticity of the earth's orbit removes us to 3,000,000 miles farther from the sun in July than in January, and causes the sun's heat upon the earth to be 6 percent more intense in January than in July. This tends to make winters in the Northern Hemisphere more mild, and in the Southern Hemisphere more severe than otherwise they would be. All these effects are well known. We may now inquire whether the recently discovered variation of the sun's emission is also of sufficient importance to affect the weather.

We have studied this question in many ways. In the Smithsonian publication called "World Weather Records" are given monthly mean temperatures and precipitations for several hundred stations in many countries. Some of these stations, as, for instance, Helsingfors, Berlin, Copenhagen, Greenwich, Capetown, and Adelaide, present observations covering nearly, or quite, a century The records of all the cities just named were studied. To avoid perplexing details, the original monthly mean observations were smoothed by 5-month traveling means. For instance, for March use

$$\frac{\text{Jan.}+\text{Feb.}+\text{Mar.}+\text{Apr.}+\text{May}}{5}$$

and for April,

$$\frac{\text{Feb.}+\text{Mar.}+\text{Apr.}+\text{May}+\text{June}}{5}, \text{ etc.}$$

The analysis of these records was very laborious, involving thousands of pages of tabular matter. As a result, however, every periodicity found in the solar variation, except one of 39½ months, was also found in the departures from normal temperature and precipitation at all these stations. In addition, periodicities of 12, 13.6, 55, and 138 months were discovered. These, like the solar periodicities, are also approximately aliquot parts of 23 years, being closely represented, respectively, by 23 years divided by 23, 20, 5, and 2. These relationships hold within the limits of accuracy to which the periods are determinable.

The magnitudes of the periodicities in temperature ranged from 0°.2 to 1°.5 C. (0°.4 to 2°.7 F.), and in precipitation from 20 to 300 percent of normal. But though so large as to be obvious, the periodicities in weather in no case continued in the same phase throughout the entire intervals of from 60 to 110 years over which the several investigations extended. On the contrary they often abruptly reversed in phase, so that the part of a period which had consistently been a maximum for many years suddenly changed into a minimum and so continued for many years to follow.

By a very lucky observation it was discovered that there is a saving regularity about these abrupt changes of phase. For if we take January 1819 as a time of departure, we find that the changes of phase tend to occur at integral multiples of 11½ years measured from that date. This is the case at all stations employed, and both for temperature and precipitation.

Figure 4 gives for Berlin the 11-month and the 21-month periodicities in temperature departures. For each of these two periodicities there are shown curves which express the results arising from successive intervals of about 11½ years from 1819 to 1930. In the case of the 11-month periodicity the forms of the curves evidently occur in pairs, so that for each 23 years at a time the temperature follows a single law in its 11-month periodicity. However, in the case of the 21-month curves, changes of form generally occur each 11½ years, though with some exceptions, as from 1841 to 1864, when for 23 years there is no marked change.

Figure 5 shows how very abrupt is the change from one form to its inverse. In the upper part of the figure are given two curves relating to the 11-month period at Berlin, representing respectively the last 22 months prior to December 1841 and the first 22 months following that date. Even in details the two curves are opposite. The first gives its maximum at the fifth month, just like the first two curves in figure 4, while the second curve of figure 5 gives its minimum at the sixth month, just like the second pair of curves in

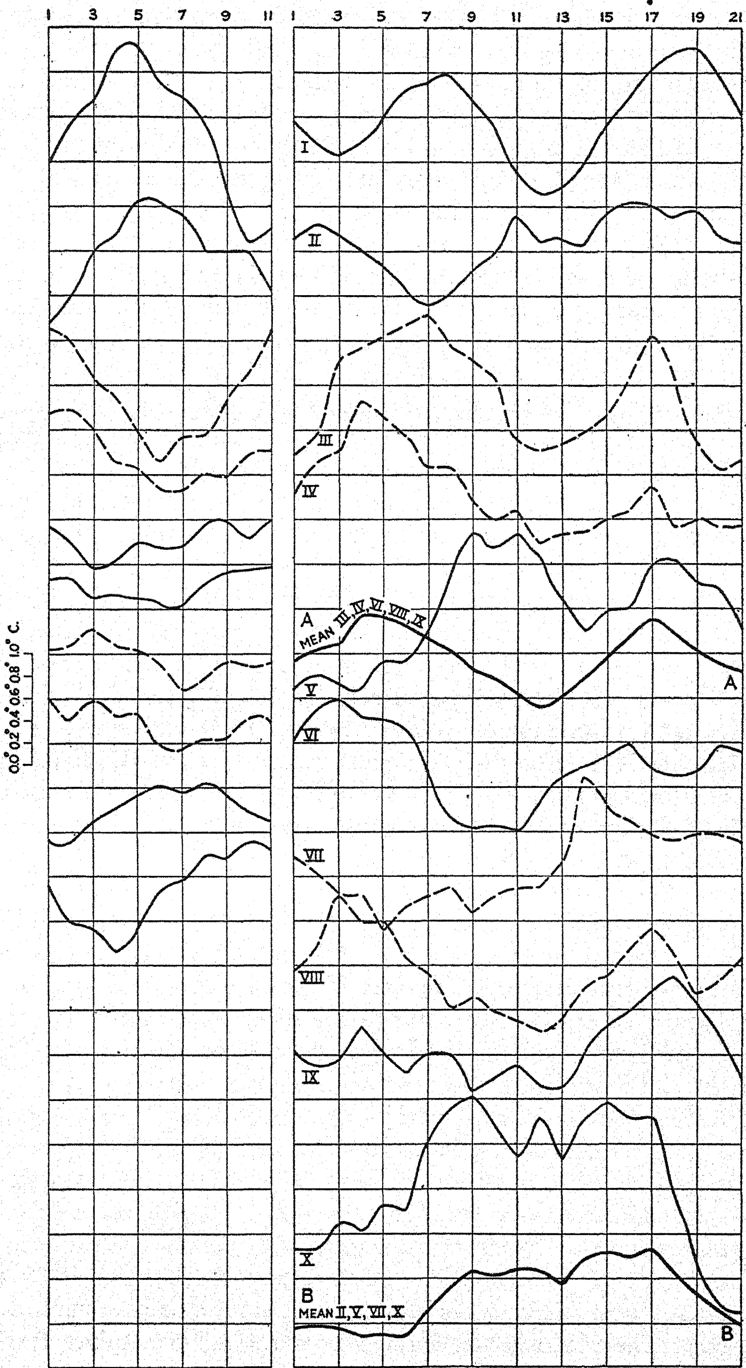


FIGURE 4.—The 11- and 21-month periodicities in Berlin temperatures. Phase dominated by the 23-year cycle from 1819. Full and dotted pairs of curves each cover a cycle of 23 years. Under A, wording should read "Mean I, III, IV, VI, VIII, IX."

figure 4. A similarly abrupt inversion is shown at the bottom of figure 5 relating to the 21-month periodicity. The third curve represents the 44 months ending with June 1864, and the lowest curve represents the 44 months beginning July 1864. The inversion, even in details, is marked, and the similarity to the corresponding mean curves covering 11½ years each in figure 4 is obvious.

As another illustration, figure 6, I give the departures from the normal of 110 years in the 12-month periodicity in the temperature of Berlin. As the 12-month periodicity is primarily due to the yearly revolution of the earth in its orbit around the sun, no one would have anticipated that the departures from its normal course would be governed by the 23-year cycle. Yet observe in figure 6 how the curves of 12-month periodic departures from normal temperature at Berlin go in pairs, each pair covering 23 years beginning 1819, and how the phases change sharply at the conclusion of each 23-year interval. Finally in figure 7 I give a complete analysis of the temperature departures at Cape Town. The phase changes are very obvious.

Having discovered that the periodicities of solar variation were also found in weather, and that all were integrally related to 23 years, both as to period and as to change of form or phase, it seemed to us appropriate to search for the 23-year cycle itself in weather and in phenomena closely related to the weather. Figures 8 to 13 show the effects of this cycle in the level of the Nile, in the levels of the Great Lakes, in the catches of mackerel and cod in the Atlantic, in the width of tree rings, and even in the thickness of varves or layers formed by the yearly settling of sediment in glacial lakes in Pleistocene geologic age.

But perhaps most interesting of all is the 23-year cycle in ordinary weather. Figure 14 shows a plot of the smoothed monthly mean percentage precipitation at Peoria, Ill., and figure 15 a similar plot of monthly mean percentage precipitation at Nagpur in central India. In figure 14 various features have been marked with letters to show their approximate repetition at successive intervals of 23 years. Besides these small details the reader may trace some principal trends of the successive curves which show much similarity 23 years apart. In figure 15 note that in 1865, 1868, and 1870 there are three pillarlike features of high percentage precipitation bounding two features of subnormal precipitation. Thus there stand out two intervals of 3 and 2 years, respectively, as if guarded by these sentinal features, but embracing besides nearly a score of subordinate features. The reader's attention is now invited to similar features, 1888–93, and 1912–17, in which nearly all the details are recognizable.

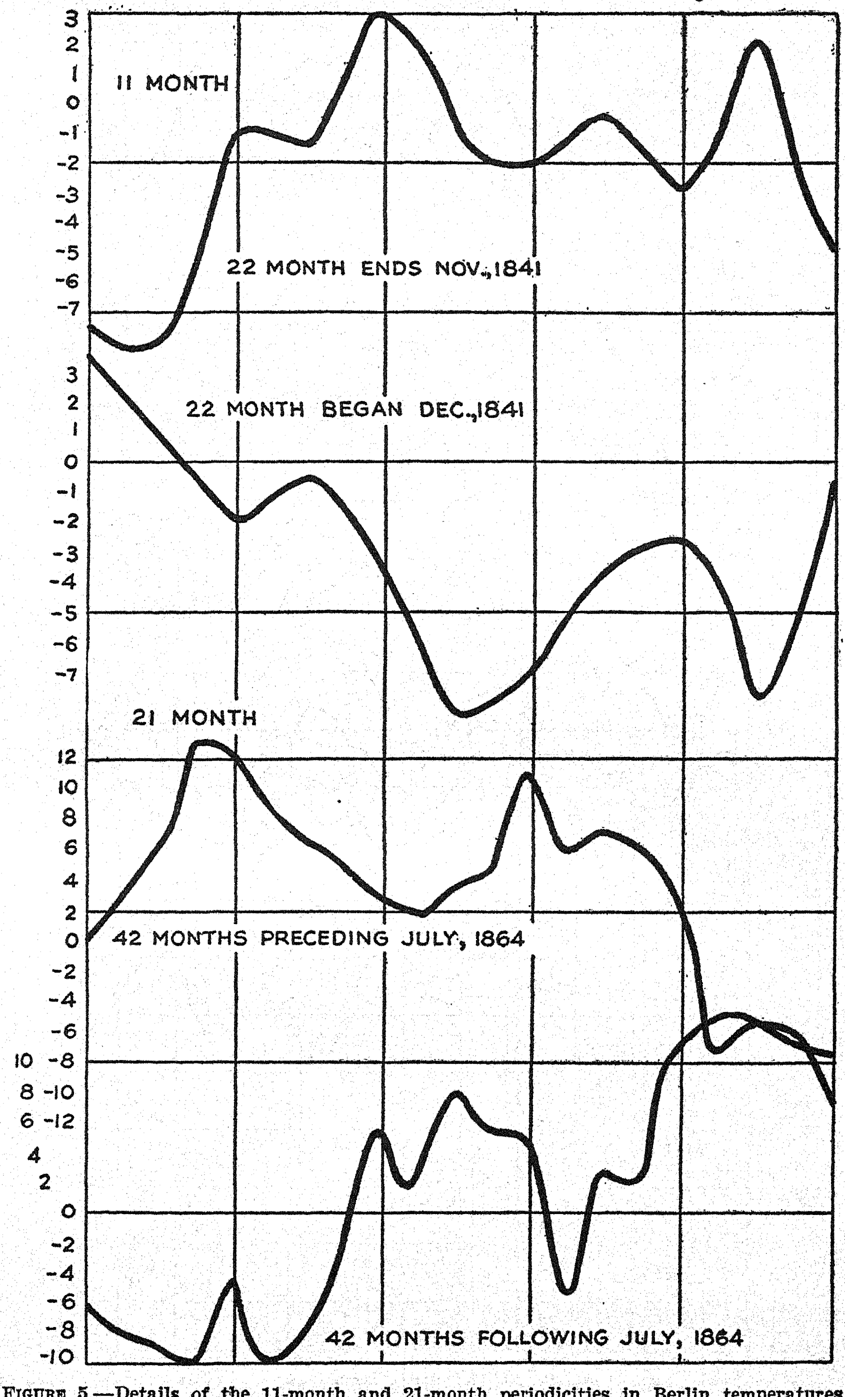


FIGURE 5.—Details of the 11-month and 21-month periodicities in Berlin temperatures. Showing abrupt reversal of phase.

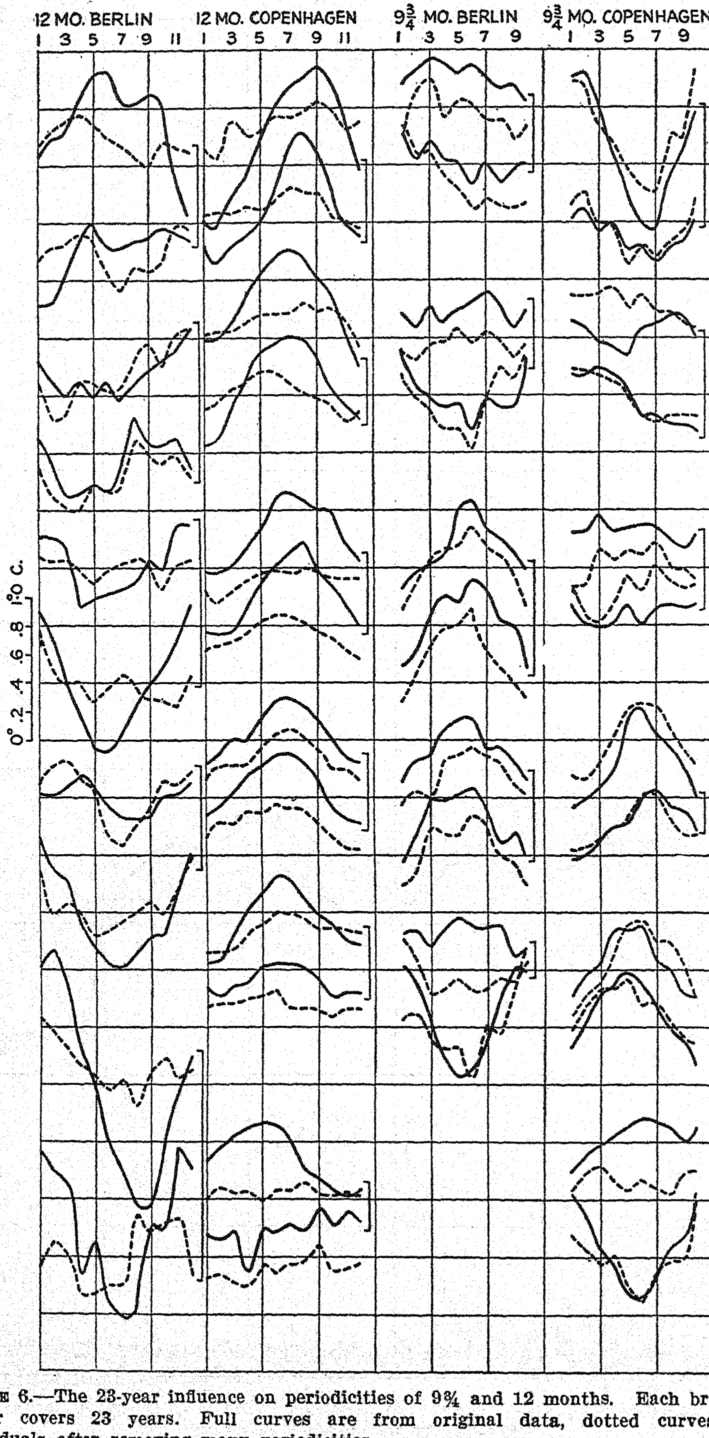


FIGURE 6.—The 23-year influence on periodicities of 9¾ and 12 months. Each bracketed pair covers 23 years. Full curves are from original data, dotted curves from residuals after removing many periodicities.

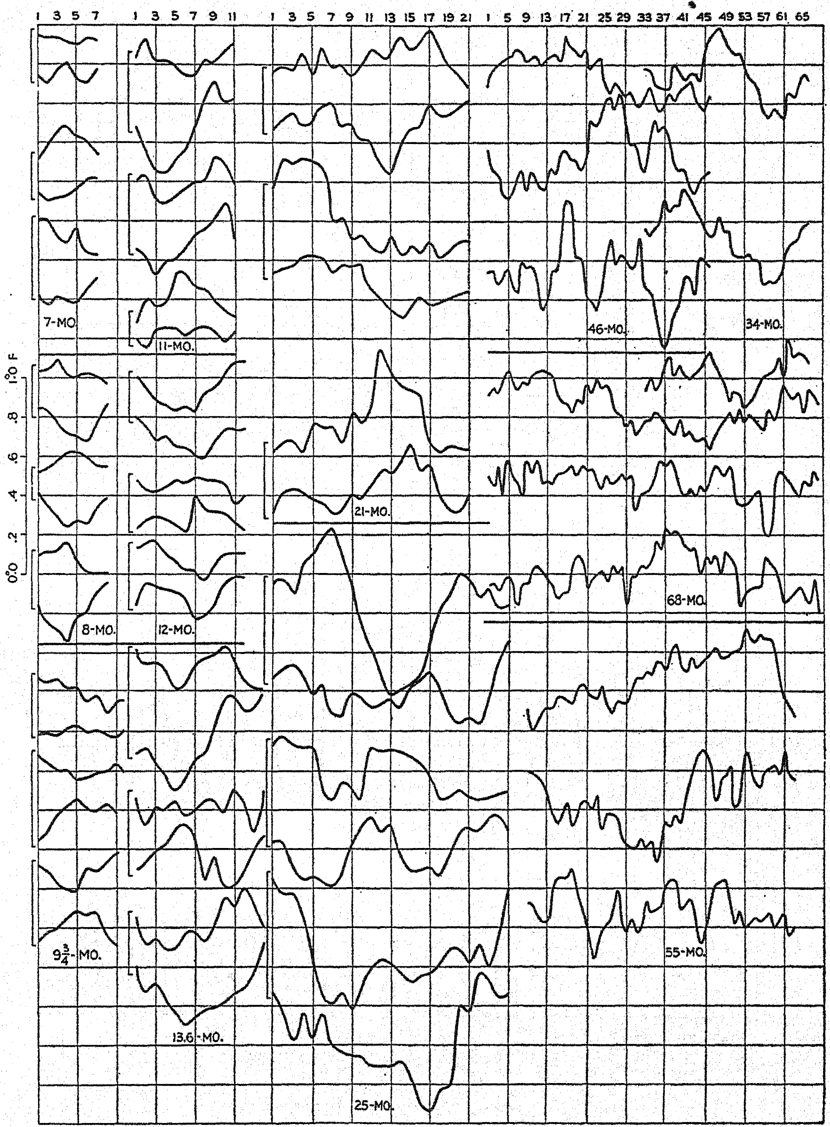


FIGURE 7.—Cape Town periodicities in temperature departures. Bracketed pairs of curves each cover 23 years. For periodicities of 34 months or over, one curve is computed for each 23 years.

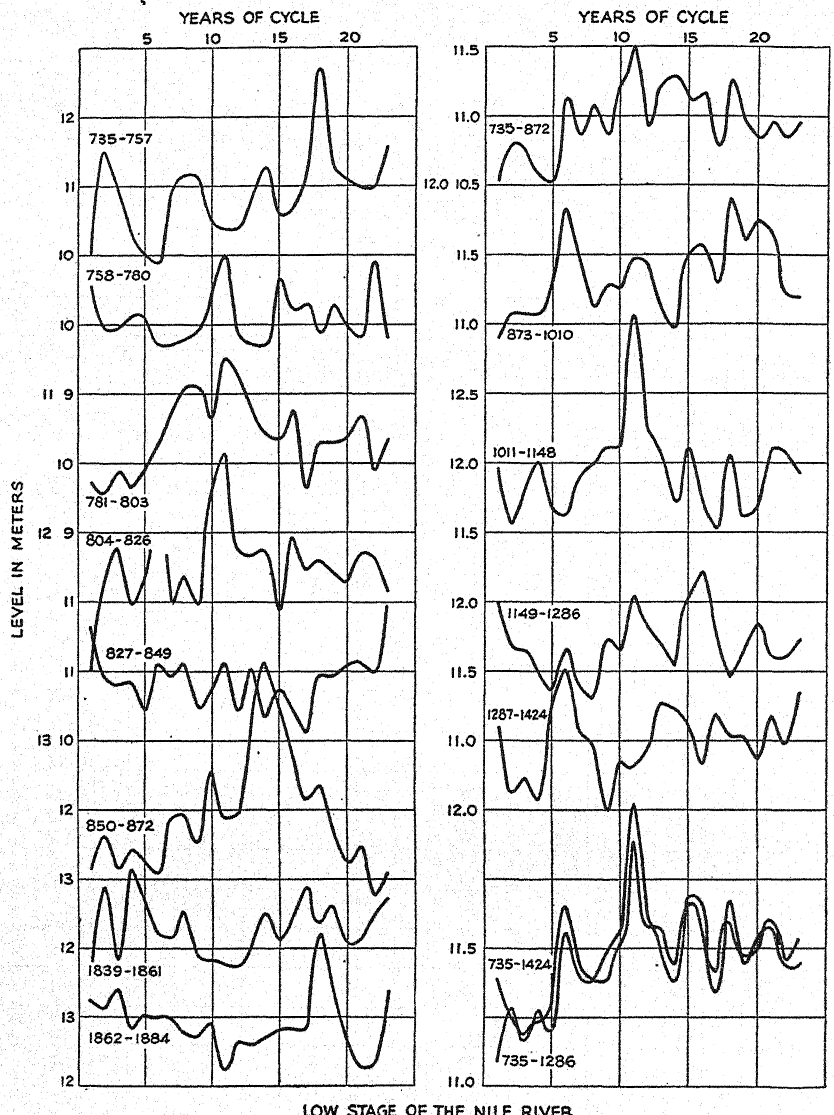


FIGURE 8.—Low-level stages of the Nile River. Showing 23-year periodicity, A. D. 725–1424 and A. D. 1839–1885.

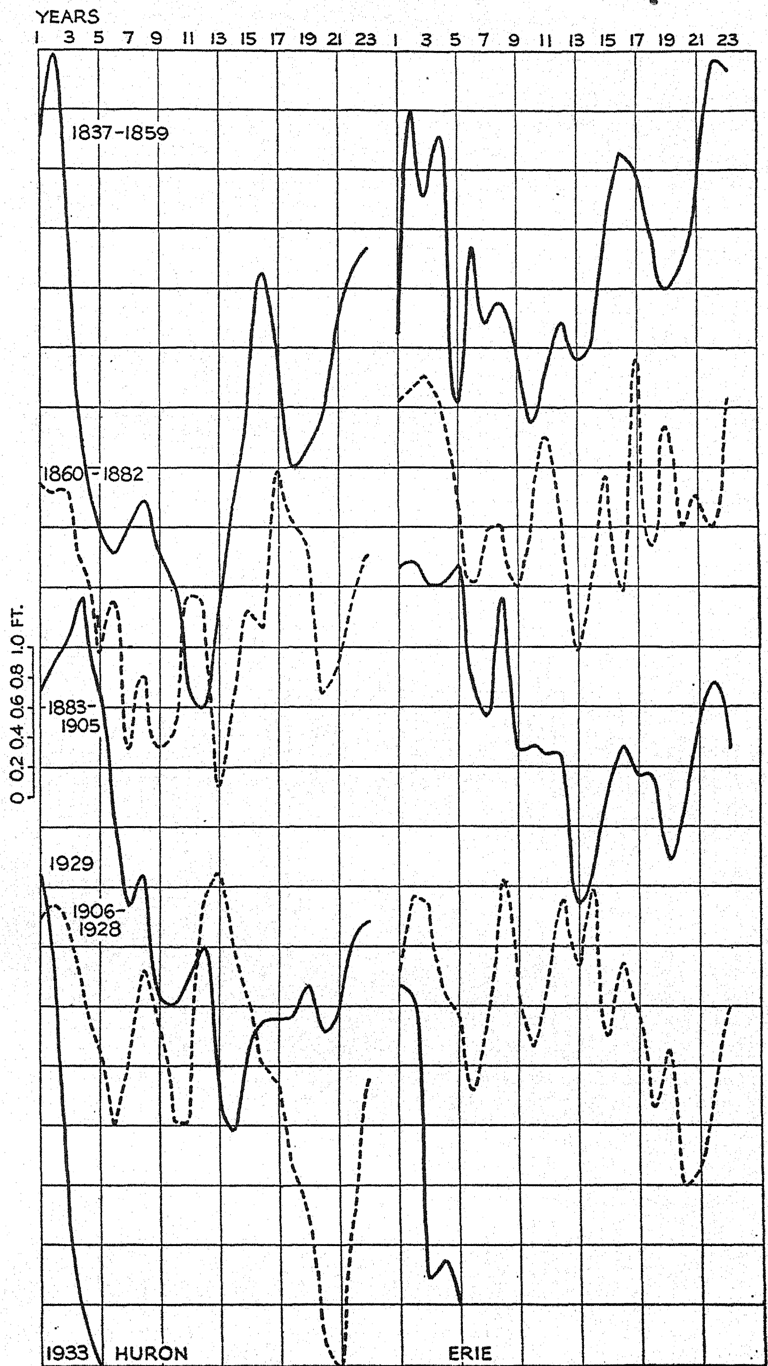


FIGURE 10.—Levels of Great Lakes, 23-year cycles. Note the marked subsidence culminating after 11 years in the full curves. The double cycle of 46 years seems important for drought conditions, see first, third, and fifth curves.

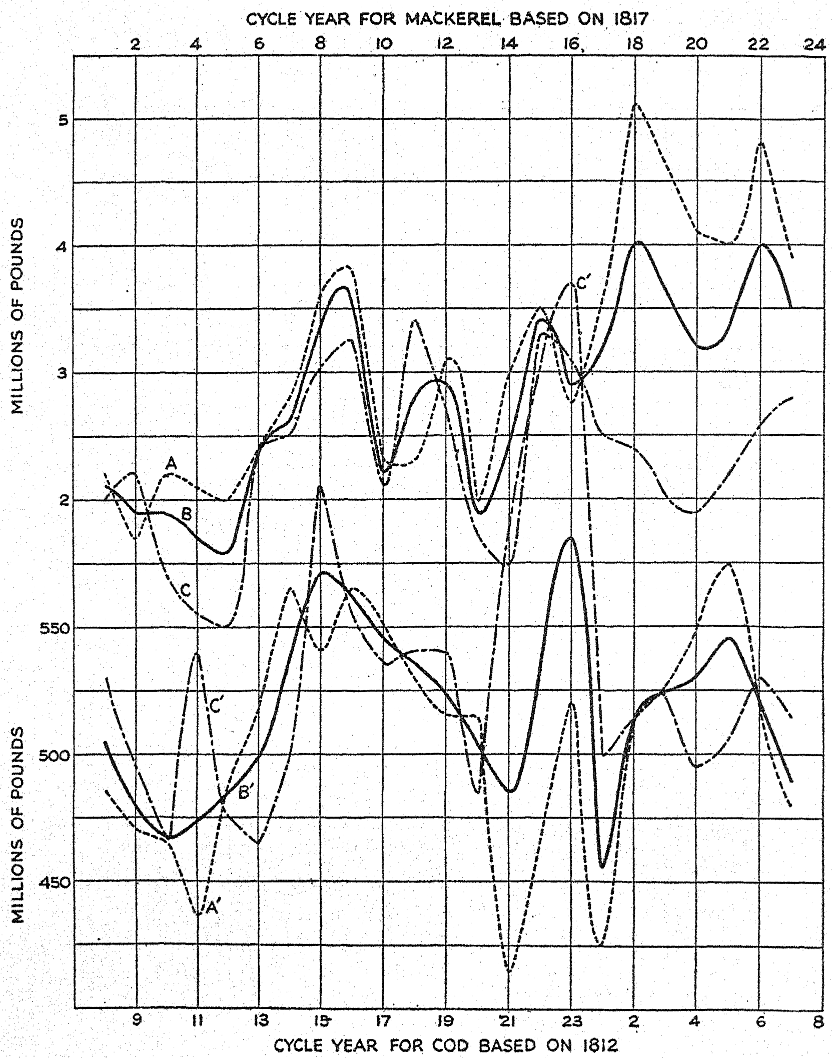


FIGURE 11.—Catch of mackerel and cod in the North Atlantic, 23-year cycles from 1812 to 1931. Curve for cod shifted in phase 2 years. Dotted curved and dashed curves are means of cycles I, III, V and II, IV respectively. Full curves are general means of all five cycles.

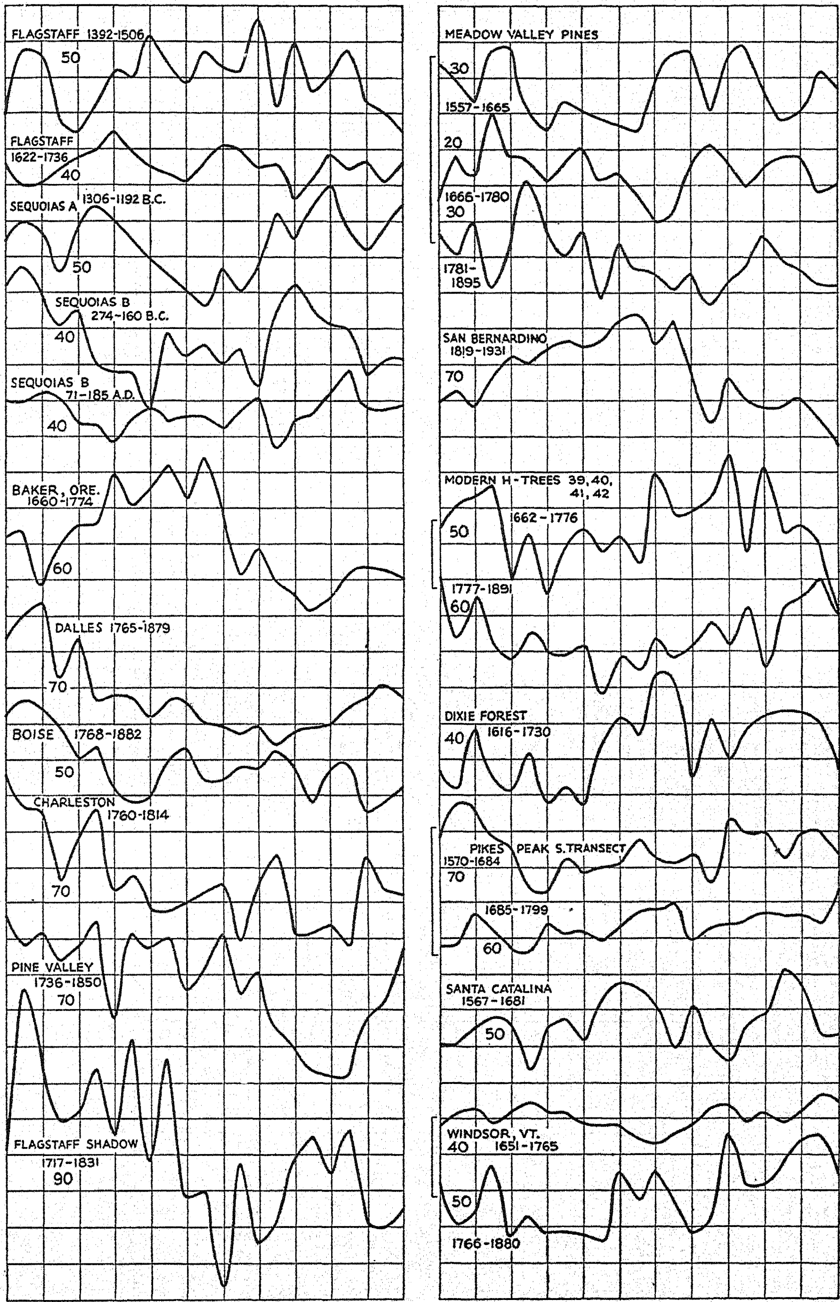


FIGURE 12.—Cycles of 23 years in tree-ring widths. Average results of 115-year intervals. Numbers indicate percentage ranges of mean values representing 115 years. Note successive curves in Meadow Valley, Modern H, Pike's Peak, and Windsor.

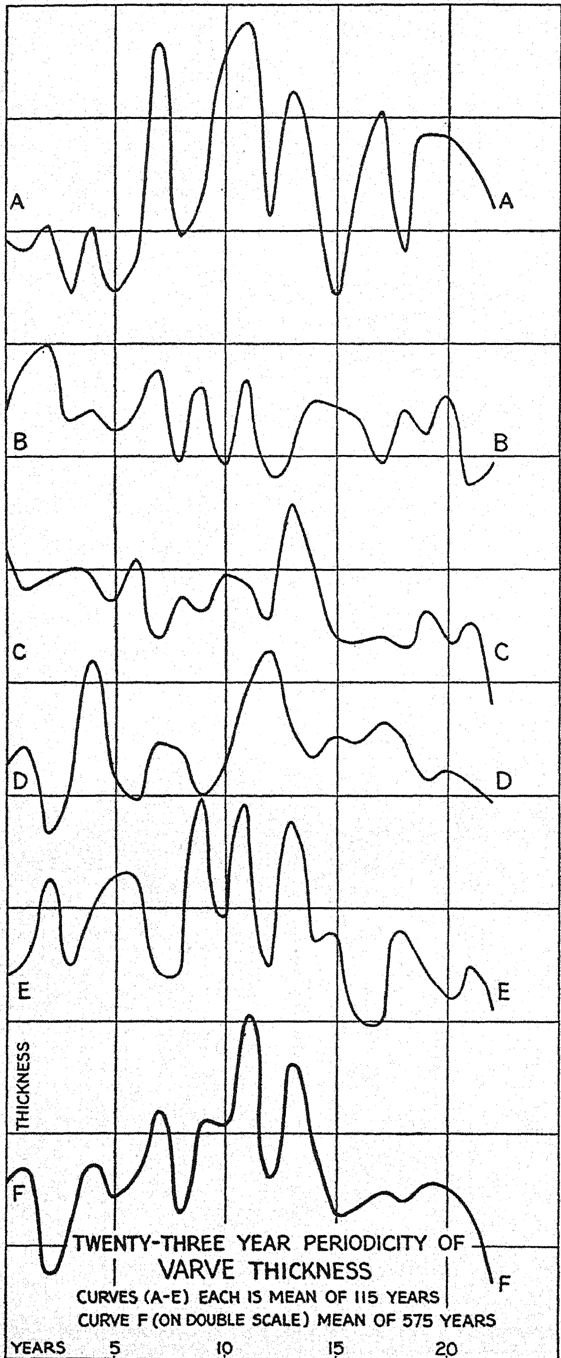


FIGURE 13.—Cycles of 23 years in Pleistocene varves. Average results of 115-year intervals.

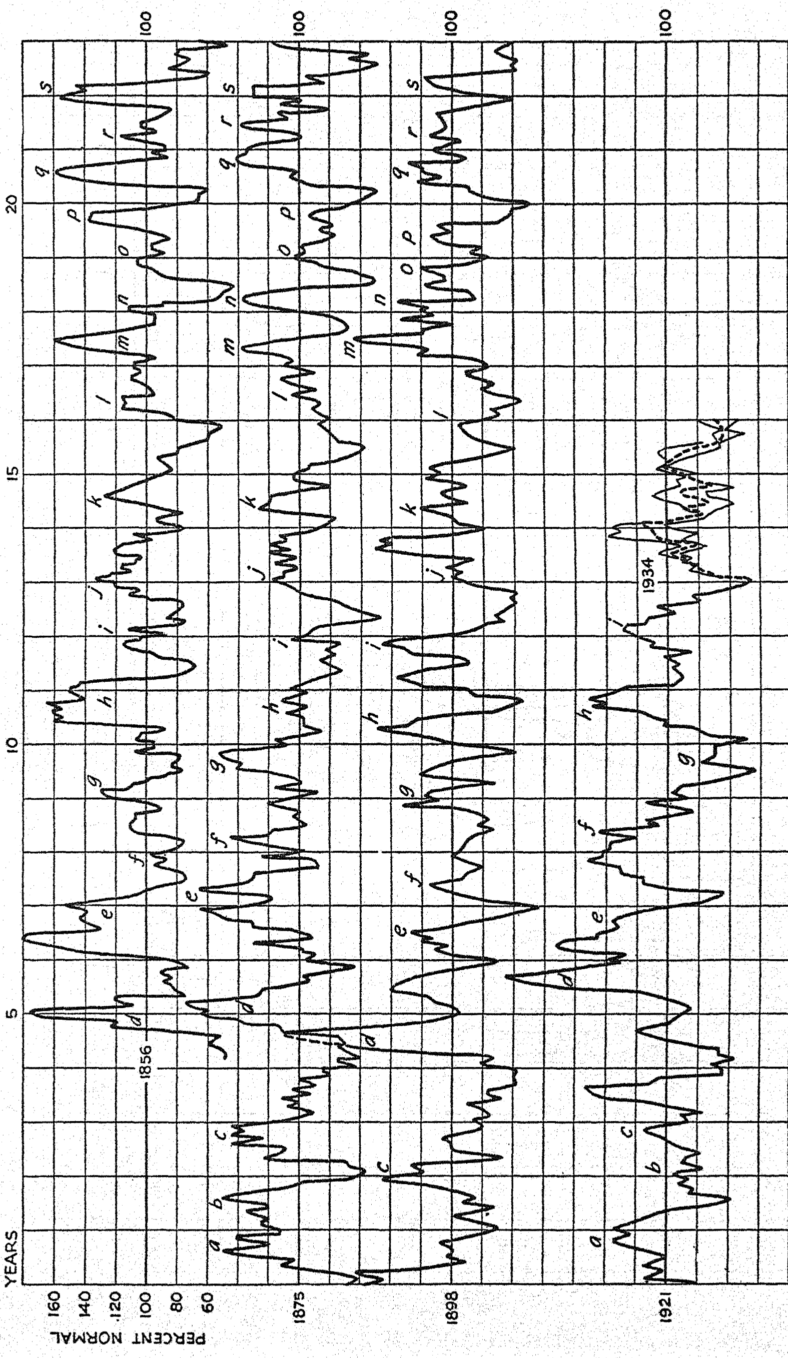


FIGURE 14.—The 23-year cycle in the precipitation of Peoria, Ill. Years 1934, 1935, 1936 predicted from previous data, and expressed by the dotted curve. Corresponding features in the several curves are marked by corresponding letters.

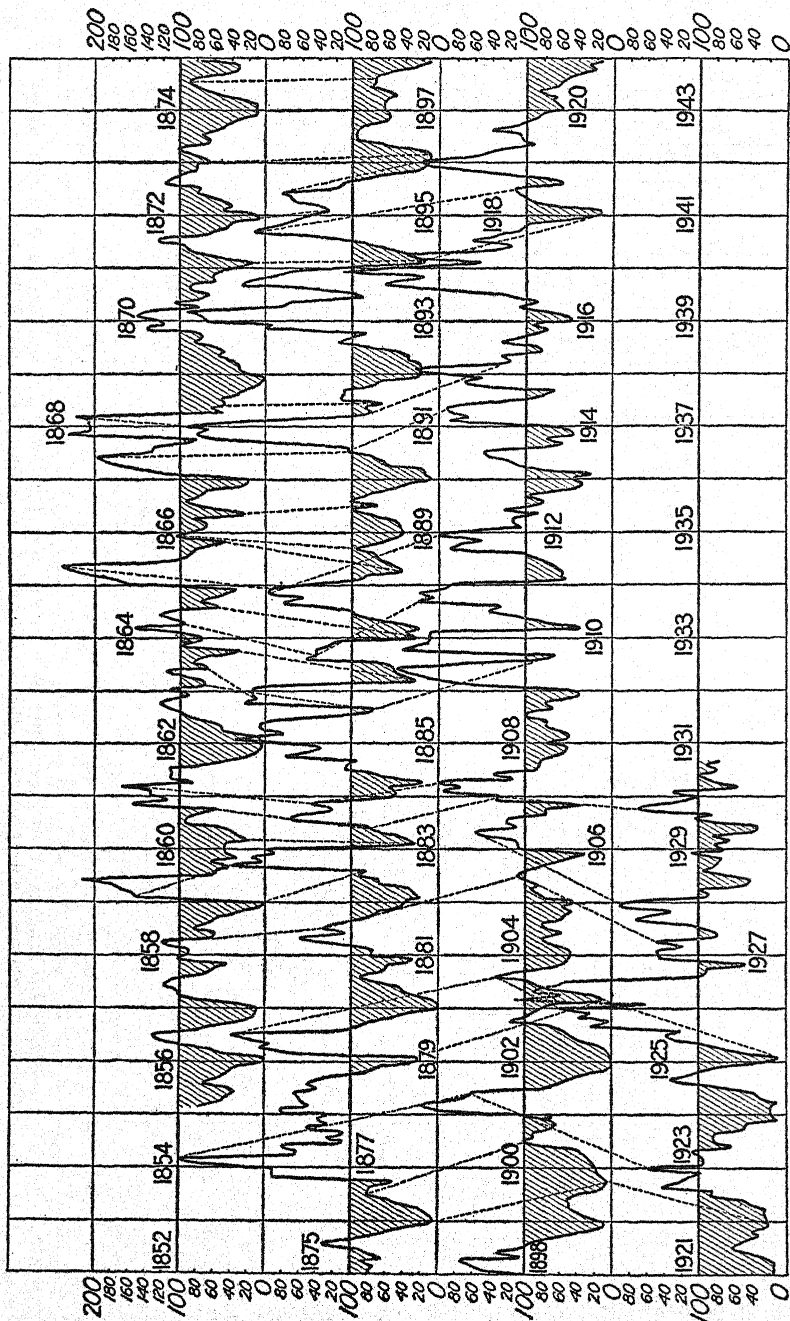


FIGURE 15.—The 23-year cycle in precipitation of Nagpur, Central India.

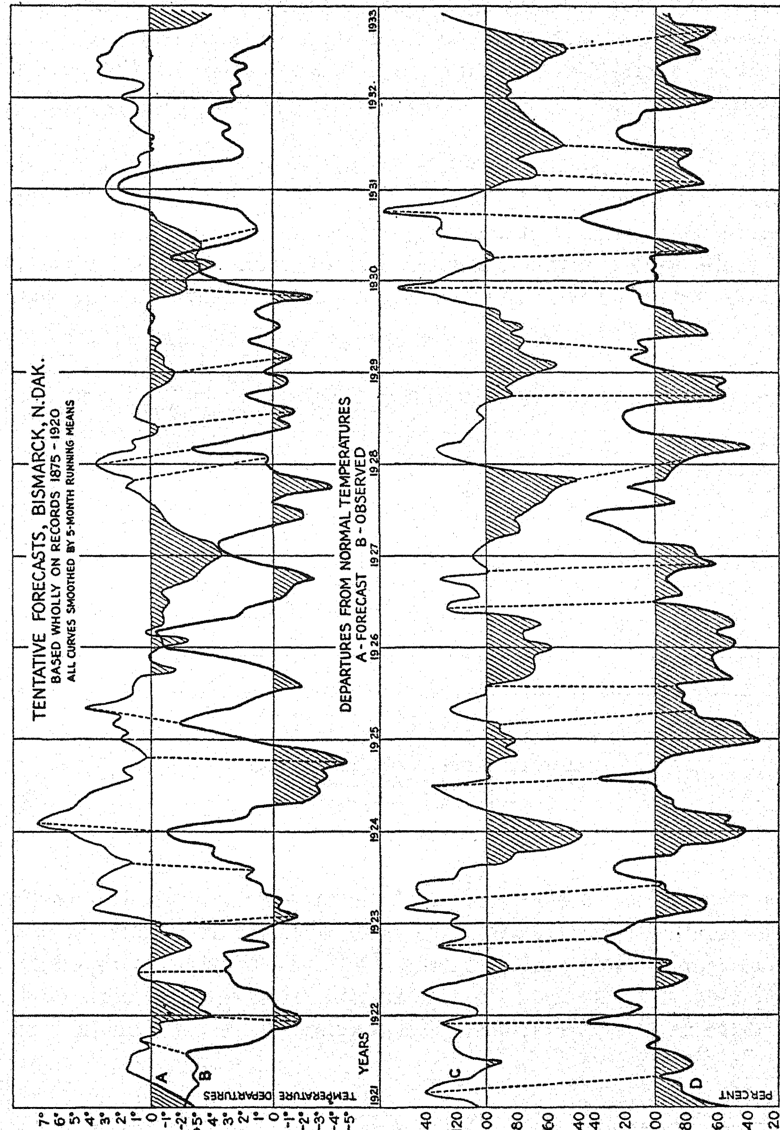
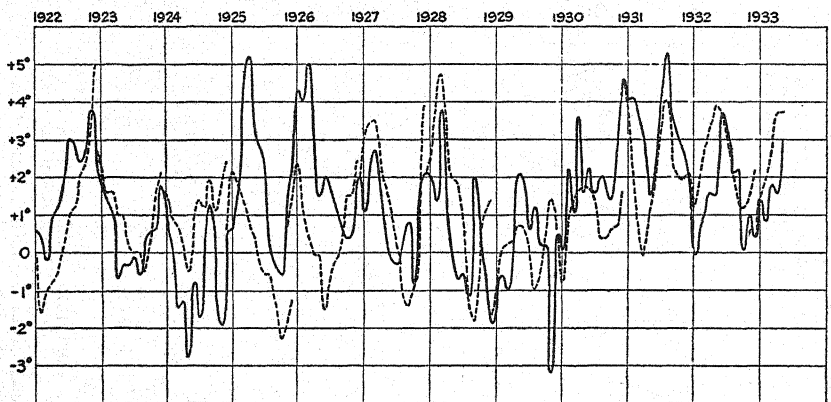


FIGURE 16.—Eleven-year forecast for Bismarck, N. Dak., with verification.

Although these repetitions of features at 23-year intervals are not precisely similar, and are sometimes displaced in phase by a few months, as in the third appearance of the sentinals at Nagpur just pointed out, yet they give some promise of value for long-range forecasting. In figure 16 I show for Bismarck, N. Dak., forecasts based on these similarities covering a period of 12 years both for temperature and for precipitation and their verifications. In figure

17 I show such forecasts made only one year in advance, and corrected to the actual event at the beginning of each year. In both figures the forecasts were made without knowledge of the events, being based solely on a study of what had happened in the preceding 46 years.

Similar forecasts have been made for over 30 stations in all parts of the United States for the years 1934, 1935, and 1936, but not published. Such sensationally important disclosures require as yet more long-continued verification of their success before it would be prudent or wise to make them public. However, the year



NORTH PLATTE, NEB.
DEPARTURES FROM NORMAL TEMPERATURE
(5-MONTH RUNNING MEANS)
—— = OBSERVED ---- = PREDICTED

FIGURE 17.

1934 having elapsed, a comparison of the predictions with the events has been made. The results have been divided into four classes. Excellent, Good, Half and half, and Bad. To illustrate this classification, I show in figure 18 a fair sample of each class both as to temperature and precipitation. The comparison resulted in the following classifications:

A. Temperature.

- Excellent, 7: Eastport, Key West, Detroit, Salt Lake City, Helena, Portland, San Diego.
- Fair, 17: Albany, New York, Washington, Hatteras, Mobile, Nashville, Cincinnati, Chicago, St. Paul, St. Louis, Omaha, Bismarck, Cheyenne, Denver, Santa Fe, Red Bluff, Spokane.
- Half and half, 3: New Haven, Galveston, North Platte.
- Bad, 4: Charleston, Little Rock, Abilene, San Francisco.

B. Precipitation.

- Excellent, 11: Eastport, Burlington, New York, Detroit, Chicago, Duluth, St. Paul, St. Louis, Little Rock, North Platte, Bismarck.

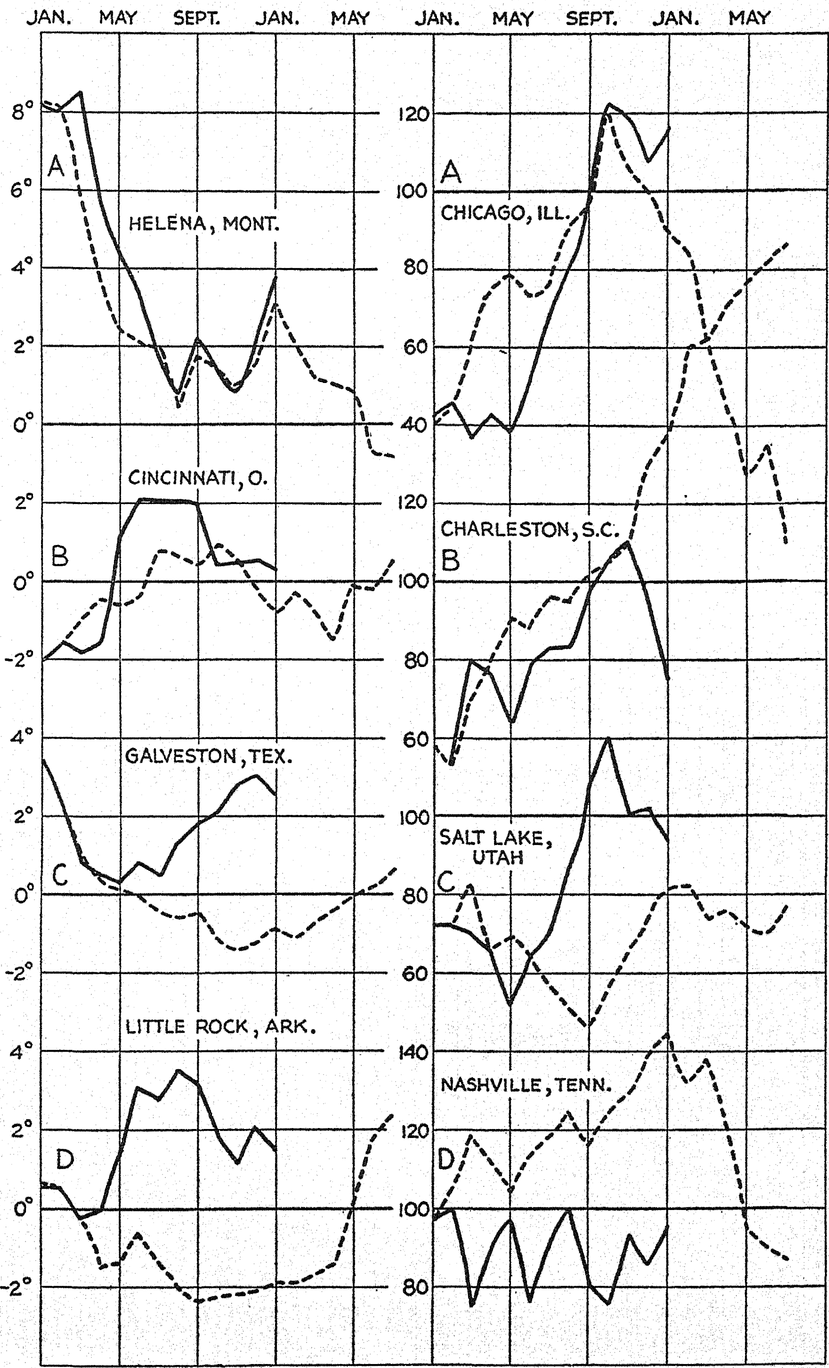


FIGURE 18.—Sample forecasts and verifications. Dotted curves are forecasts. Grades of results: A, excellent; B, fair; C, half and half; D, bad. Left, temperature; right, precipitation.

TABLE 1.—*Comparison of solar and terrestrial periodicities*

Period	Ranges (observed and percentage)										Ranges in percentage as ratios of solar ratios expressed in percentage			
	Solar		Berlin		Greenwich		Cape Town		Adelaide					
	Calories	Percent	Centigrade	Percent	Fahrenheit	Percent	Fahrenheit	Percent	Fahrenheit	Percent	Berlin	Greenwich	Cape Town	Adelaide
			°		°		°		°					
8 months	0.004	0.21	0.5	0.17	0.6	0.12	0.6	0.12	0.3^{5}	0.07	81	57	57	33
11 months	9	.47	1.0	.35	0.6^{5}	.12	0.2	.04	0.3^{5}	.07	75	26	9	15
21 months	10	.52	1.2	.41	1.8	.31	0.7^{5}	.14	1.9	.36	79	60	27	69
25 months	7	.36	1.6	.55	1.4	.27	1.2	.23	1.4	.27	153	74	64	75
34 months	7	.36	1.2	.41	0.7	.13	0.5	.10	1.3	.25	114	36	28	70
46 months	10	.52	1.6	.55	1.2^{5}	.24	1.0	.21	1.4	.27	106	46	39	52
68 months	10	.52	1.2	.41	0.4	.08	0.5	.10	0.8	.15	79	15	19	28
92 months	10	.52	1.2	.41	1.0	.21	0.6^{5}	.12	1.4	.27	79	40	23	52
Mean percentages											96	44	33	50

B. Precipitation.—Continued.

Fair, 11: New Haven, Albany, Philadelphia, Washington, Charleston, Peoria, Galveston, Santa Fe, Denver, San Francisco, Spokane.

Half and half, 8: Key West, Cincinnati, Omaha, Helena, Salt Lake City, San Diego, Red Bluff, Portland.

Bad, 5: Hatteras, Mobile, Nashville, Abilene, Cheyenne.

Doubtless readers will wish to inquire whether it is reasonable that periodicities of small amplitude in solar variation, such as those shown in figure 2, are competent to produce temperature changes as large as those found. In the following table, I give a percentage analysis of this question. Unconsciously, when we think of the temperature, we base it approximately on the zero of the ordinary thermometer, so that a change of 5° F. seems to us as if it were a change of 5 percent or more in temperature. Really we should consider the temperature as measured from the absolute zero. This is −273° of the Centigrade scale and −523°.4 F. Thus a Fahrenheit temperature of 70° is really 593°.4 Absolute, and a change of 5° is only about 1 percent in temperature.

The table shows that though the ranges of the periodic changes in solar radiation are all less than 1 percent, so too are almost all the corresponding changes in temperature. Indeed, if measured in percentages, the temperature changes average but from one-third to nine-tenths as great as the changes in solar radiation. On the whole, the relationship does not seem unreasonable and leads us to the remarkable conclusion that an important and perhaps a major part of the departures from normal, which make up weather as distinguished from climate, originate in these newly discovered variations in the radiation of the sun. If so it is clear that long range weather prediction is impossible if based solely on the earth's conditions, excluding solar variation as a factor.

36923—36——9

SEASONAL WEATHER AND ITS PREDICTION [1]

By Sir Gilbert T. Walker, C. S. I., F. R. S.

I have chosen the subject of seasonal weather for my address, because its economic importance is obvious to most men who have lived in the Tropics, and its scientific problems are full of interest. Unfortunately there is an additional motive, the need of warning against dangers ahead. For the difficulties of long-range forecasting are not in general adequately recognized, so that some of the most progressive countries in the world are inclined to make predictions on an insecure basis; their technical staff does not realize that though the prestige of meteorology may be raised for a few years by the issue of seasonal forecasts, the harm done to the science will inevitably outweigh the good if the prophecies are found unreliable. We only learn from experience that while the forecasting efforts of a charlatan are judged by their occasional successes, it is the occasional failures of a government department which are remembered against it.

In a country where conditions are as changeable from day to day as they are here, it is natural that we should think in terms of wet or fine days rather than of wet or dry periods; but in the greater part of our empire the different seasons are much more sharply defined, and so their dominant features stand out more clearly. Also the variability of their seasons is in general materially greater than here. Thus, in the annual rainfall measurements of the last half century the smallest rainfall of Great Britain has been 23 percent below normal; but that of large areas in South Africa has been in defect by 40 percent, in northeast Australia by 50 percent, and in the Punjab by as much as 58 percent, or two and a half times that of this country.

Now, a season that is unusual seems to have some abnormal factor permanently at work diverting the weather from its ordinary course; in India I found, when issuing the daily forecast in a dry winter,

[1] Presidential address before the section of mathematical and physical sciences, British Association for the Advancement of Science. Reprinted by permission from the Report of the Association for 1933.

that I had at times to predict no rain, when with identical conditions as shown by the weather map I should in a wet winter have predicted a widespread fall. Even in England, in winter, there is an appreciable persistence in the characteristics: During the last 60 years the 15 wettest Januarys were followed by Februarys of more than average rainfall in 10 cases; and with dry Januarys also there is a similar two-to-one chance of a prolongation of the character. It is this persistence, especially when it is preceded by abnormal features in other regions, that seems now to hold out most promise of reliability in forecasting. In agricultural countries in which a failure of the rains involves a national calamity, the desirability of making preparations in advance has long ago led to efforts at prediction; and the demand has been so great that the supply has been forthcoming before its quality would bear the most cursory examination. The causes of unusual weather seem hopelessly obscure to the layman; and hence primitive ideas, surviving in the depth of our natures from countless ages of magical practices, still come to the surface in connection with it. In India I have been officially asked what is the need of an expensive and difficult scientific inquiry into the causes of drought when Hindu astrology will indicate what is coming; and many a country that claims to be dominated by western science fails to recognize that events in weather obey the ordinary laws of physics and chemistry. The almost universal idea that weather must repeat itself after a certain number of years finds its origin, I believe, ultimately in the ancient belief in the control of our affairs by the heavenly bodies with their definite cycles—a belief which clearly shows itself in the supposed influence of the moon on the weather. Be that as it may, the faith in periods is so deep-seated that even in scientific discussions the ordinary tests for validity are very often ignored: More than once I have seen in journals of repute the artless remark of an author that if he were to limit his results to those which would satisfy the criteria of reality he would obtain few results of interest.

Another regrettable feature of current practice, even in important memoirs, is that of classing together processes with true periods and those sometimes called "quasi-periodic", of which the period varies. If our ideas are to be applied with success in the present enterprise their currency must be stabilized, and no good can come of attempting to pass off a vague surge of a few years as a 3-year period.

After these preliminary remarks I propose to make a rapid sketch of the relationships that have been found between seasonal features in different parts of the world, then to describe the efforts that have actually been made to issue long-range forecasts, and finally to consider the directions from which improvements can be hoped for.

In the collection of World Weather Records, of which the publication was made possible by American generosity 6 years ago, there are about a thousand series of monthly data of pressure, temperature, and rainfall; and these form but a scanty network. If quarterly values were computed and correlation coefficients between each pair for contemporary seasons, as well as for seasons one quarter before and after, we should have about 4,000,000 coefficients. Coordination and generalization are imperatively called for, and the development of the subject lies in the discovery of regions over which the variations are linked together.

After preliminary efforts by Buchan, Hoffmeyer, Blanford, de Bort, Hann, Meinardus, and Pettersson, the far-reaching possibilities were first visualized by Hildebrandsson, who plotted pressure curves for 10 years of 68 stations scattered over the world and drew attention to the relations between them; among these the opposition between Sydney in Australia and Buenos Aires was fated to have great influence; his subsequent studies involved temperature and rainfall also. In 1902 the Lockyers confirmed the existence of the see-saw between pressure in the Argentine and in India or Australia; and using graphical methods produced a world map, dividing areas in it according as their pressures varied with India or South America. They were followed by Bigelow's study of relationships with solar prominences. During recent years considerable development has followed the introduction of statistical methods, particularly in the hands of Exner, and of members of the meteorological services of England and India.

It will be convenient if I may here introduce a technical phrase. If we have two series of numbers of which the variations are connected, there will be a certain proportion of the variations of each which are associated with those of the other, and this proportion is called the correlation coefficient between the series. If it is nearly unity the numbers vary closely together; if it is small there is little relationship between them; and if it approaches -1 the relationship is close, but one series goes up when the other goes down.

Let us now consider some of the results of the analysis of seasonal features. It has long been known that in the North Atlantic Ocean there are two types of winter. In one, pressure is high near the Azores and southwest Europe, and low in Iceland, while temperatures are high in northwest Europe; in the other type all these features are reversed. (See the three upper graphs in fig. 1.) Let us suppose that we want to know the effect of these types on, say, temperature in Labrador. An obvious plan would be to plot the variations in successive winters, December to February, of the quantities which increase together, such as Vienna pressure and

Stornoway temperature, and also of the quantities which decrease when the former increase, such as Iceland pressure, reversing these so as to secure similarity of the graphs. We could then draw a graph which is the mean of all these, and could regard it as expressing the variations of the North Atlantic fluctuation as a whole. (See the lowest graph of fig. 1.) If now we were to plot Labrador temperature below it we should see that its variations were, like those of Iceland pressure, strongly opposed, and on reversing Labrador there would be very strong similarity. So Labrador becomes a good example of the second group. Now we want to know the

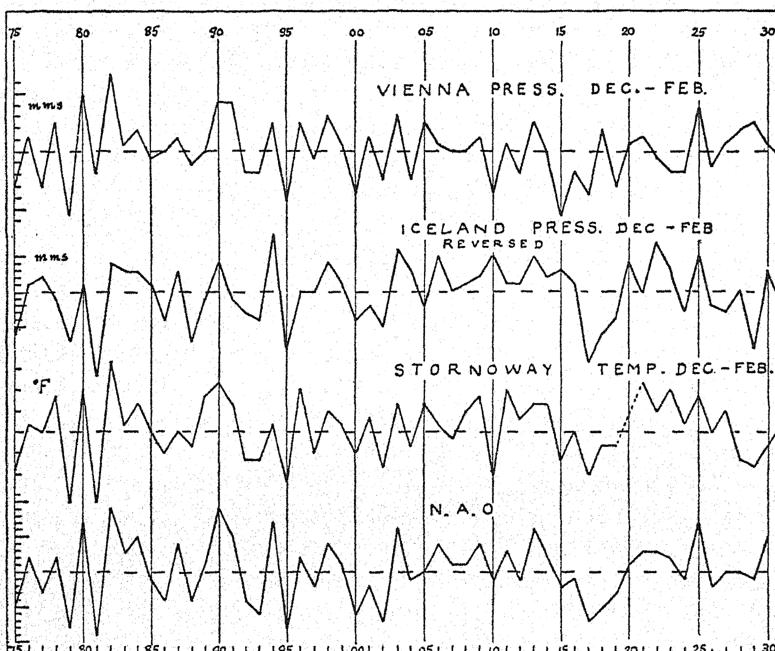


FIGURE 1.—North Atlantic oscillation.

effect of the North Atlantic oscillation on the pressure, temperatures, and rainfall of a large number of places; and if in this way we put a hundred graphs under one another, some easy to classify and some doubtful in character, it would be difficult to draw satisfactory conclusions in a manner capable of convenient and accurate expression. So instead of graphs we use numbers. Having found by preliminary investigation the stations which are most representative, we calculate the figures in successive years for the North Atlantic oscillation as a whole, and then work out the correlation coefficients of this with the pressures, temperatures, and rainfalls of all the places in which we are interested. These coefficients are plotted in figure 2, and in its top chart we see that the rise of

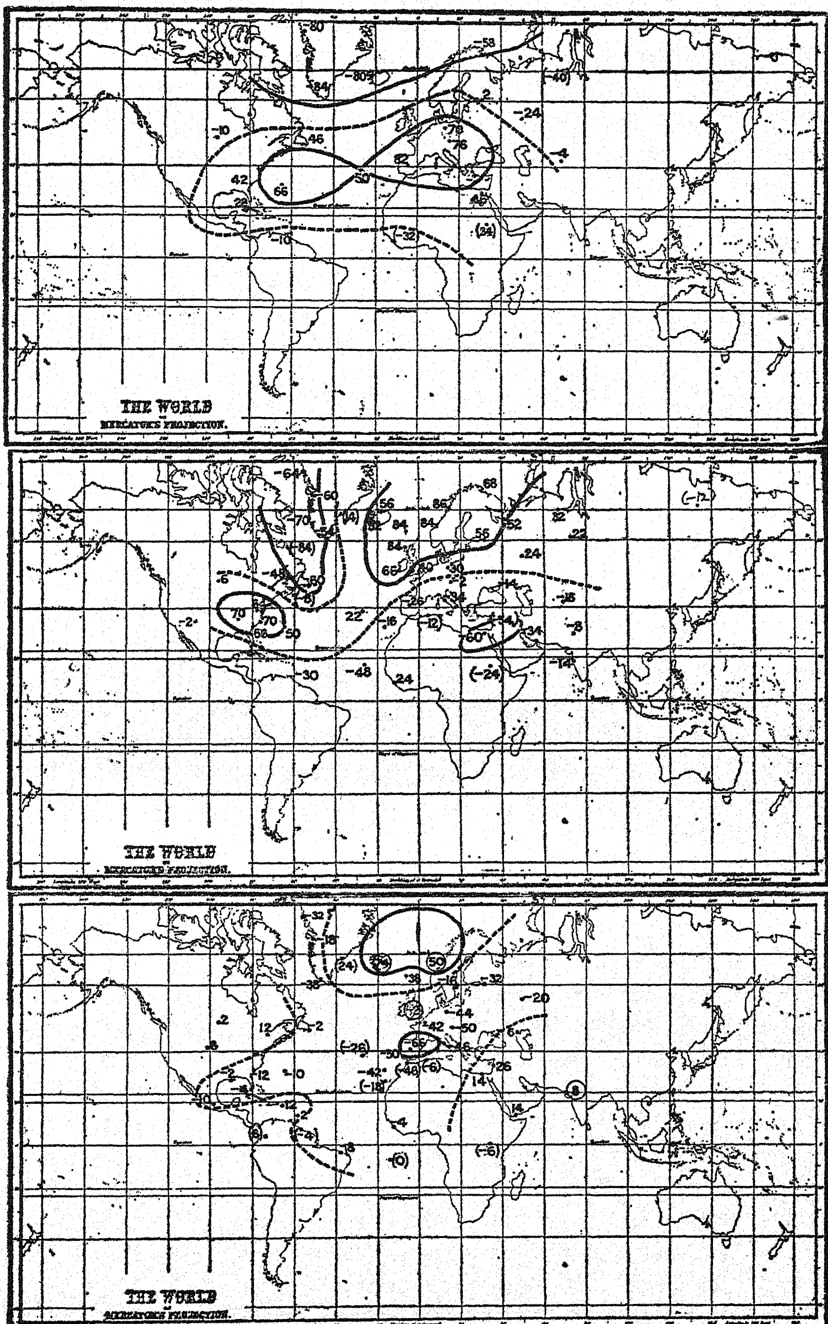


FIGURE 2.—Relations of North Atlantic oscillation with contemporary pressure, temperature, and rainfall of December to February. Numbers based on series shorter than 30 years are in brackets; those for areas are in circles.

pressure with a positive fluctuation is greater as far east as Vienna and as far west as the Bermudas than it is at the Azores. There is also to be seen in the second chart conspicuous warmth in the east of the United States as well as in northwest Europe, and marked cold to the southeast of the Mediterranean as well as along the northeast of North America. On rainfall, in the lowest chart, the influence is less wide-spread. The small amount of persistency is shown in figure 3. The first of its three graphs shows how close are the relationships of pressure in December with the figures expressing the fluctuations of the North Atlantic in that month; the second and third, which give the relationships of pressure and temperature in January with the fluctuations of the oscillation of the December before, show that little effect of the December conditions continues after a month.

The more critical in my audience may object that if you are sufficiently astute in choosing your successive numbers for the fluctuation you can make a certain amount of agreement with any system of pressures and temperatures; and to this the reply is that the fit is very much closer than can be explained in this way. Others may urge that all these arguments are merely numerical, and quote the jibe that by statistics you can prove anything. But if you wish to understand phenomena you must collect the facts, and if they are numerical it is only in the very simplest of cases that you can see relationships by merely plotting curves and comparing them. Statistical methods are inevitably forced on us by common sense when we want accurate and reliable inferences from series of data, just as a sextant is forced on a sailor when he wants to determine accurately the altitude of the sun. One who has lost an important lawsuit, owing to the ingenious argument of the opposing counsel, may object that by logic you can prove anything; but that is an indequate defense for being illogical on all occasions. As a matter of fact, when studying relations of cause and effect statistical methods show us what quantities vary together, but strictly by themselves they tell us nothing as to causation. If we compare heights of fathers and sons, we learn that tall sons have tall fathers; but in spite of that fact we are not convinced that the child is literally father to the man.

Let us consider an example from data published in 1906 regarding unemployment and illiteracy as measured by the percentage of persons who could not sign their name in the marriage register (fig. 4). Clearly the correlation coefficient between these two factors might lead to most undesirable inferences regarding the usefulness of education. But we could not expect to arrive at the truth if we ignored such an important fact as the amount of trade, and on admitting the data of this factor we see at once that faith in the value of our ele-

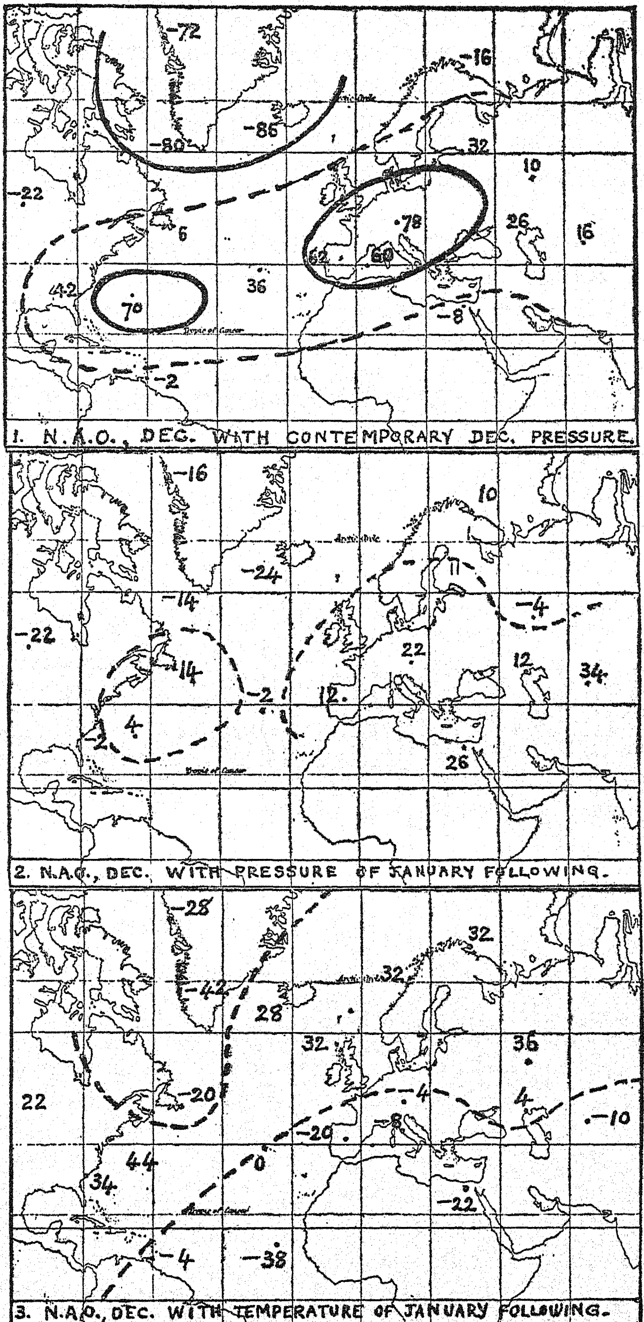


FIGURE 3.—Relations with the North Atlantic oscillation of December.

mentary schools need not be uprooted; for the revival of prosperity produced marriage, especially among those in a humble position who could not write, as well as a decrease in unemployment; so that the last two factors varied similarly. We see, then, that we may be misled if we do not take into account all the factors that may be operative. In other words, statistical methods like logarithm tables are invaluable as a tool for giving correct numerical results with the minimum of mental labor; but neither tool possesses imagination or judgment, and neither of them is a substitute for expert knowledge of the subject to which it is applied.

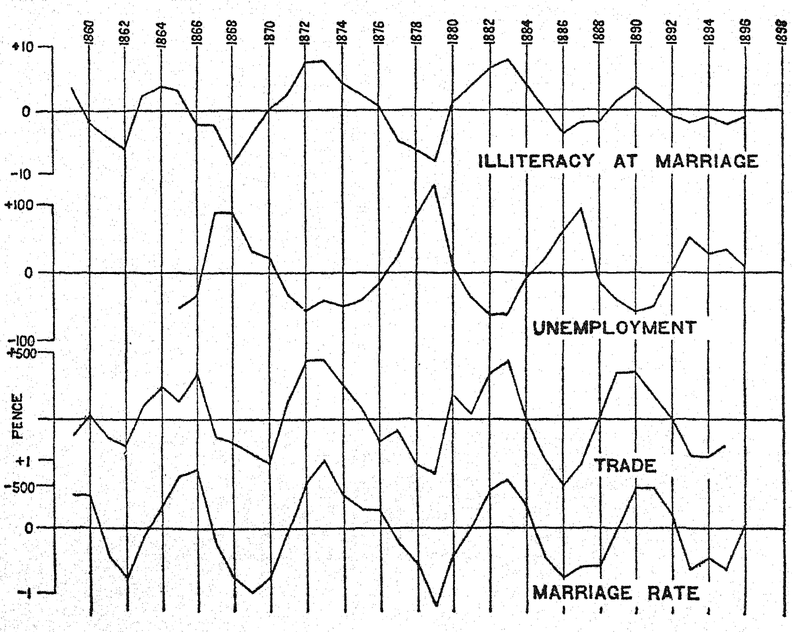


FIGURE 4.—Illiteracy and unemployment.

Let us now turn to the North Pacific Ocean, which, in spite of its limited access to the Arctic seas, is subject to fluctuations very similar to those of the North Atlantic. A similar treatment yields figure 5, in which increased pressure gradients go with high temperature to the northeast and southwest, and low temperature to the northwest and southeast. It will be noted that in both the North Atlantic and Pacific Oceans a fluctuation is classed as positive when the pressure gradient is strong and the wind circulation is active.

The largest known system of related seasonal weather is that called the "southern oscillation" (or "southern fluctuation"), which has features in the southern summer of December to February somewhat different from those of the southern winter of June to August. It will be seen in figures 6 and 7 that at both times of the year the

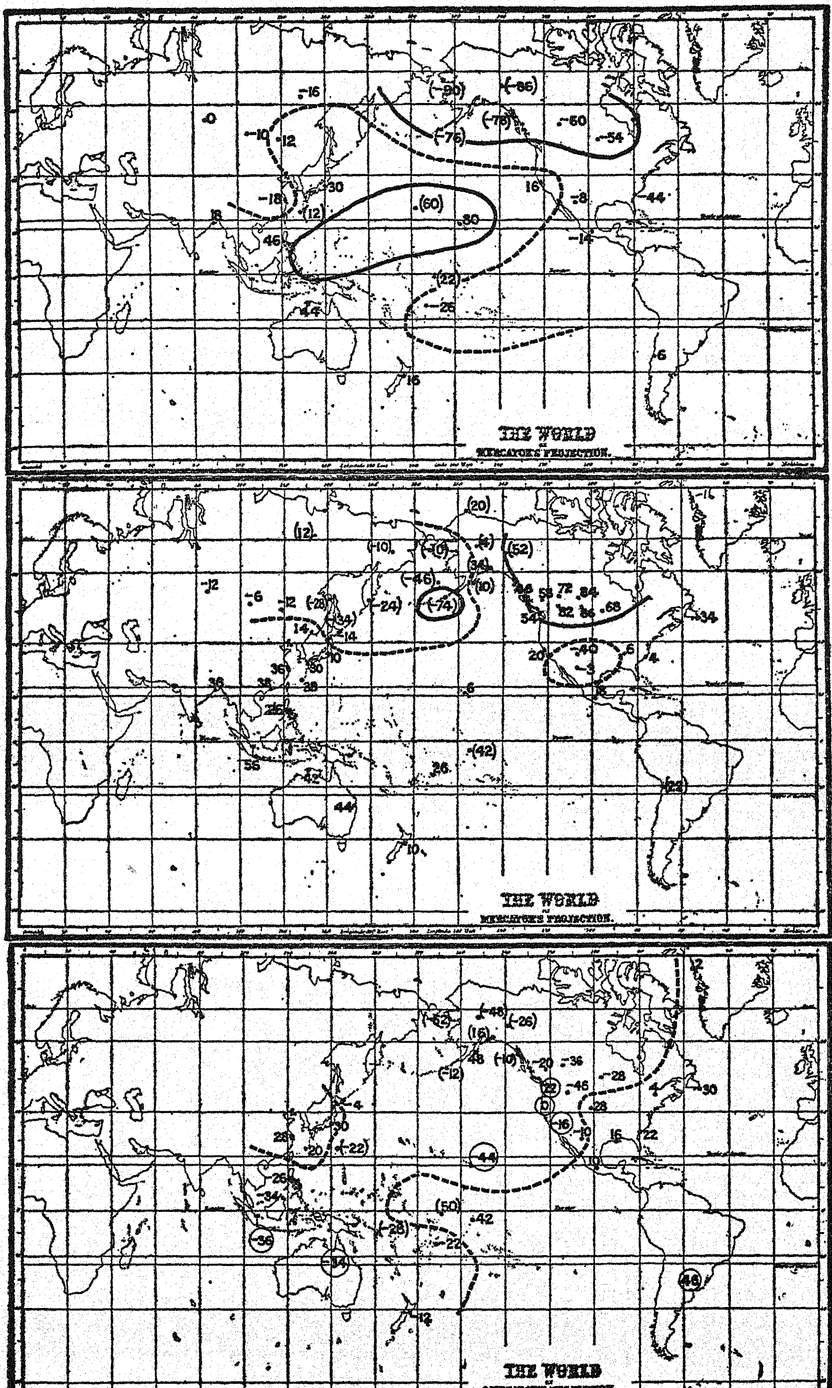


FIGURE 5.—Relations of North Pacific oscillation with contemporary pressure, temperature, and rainfall.

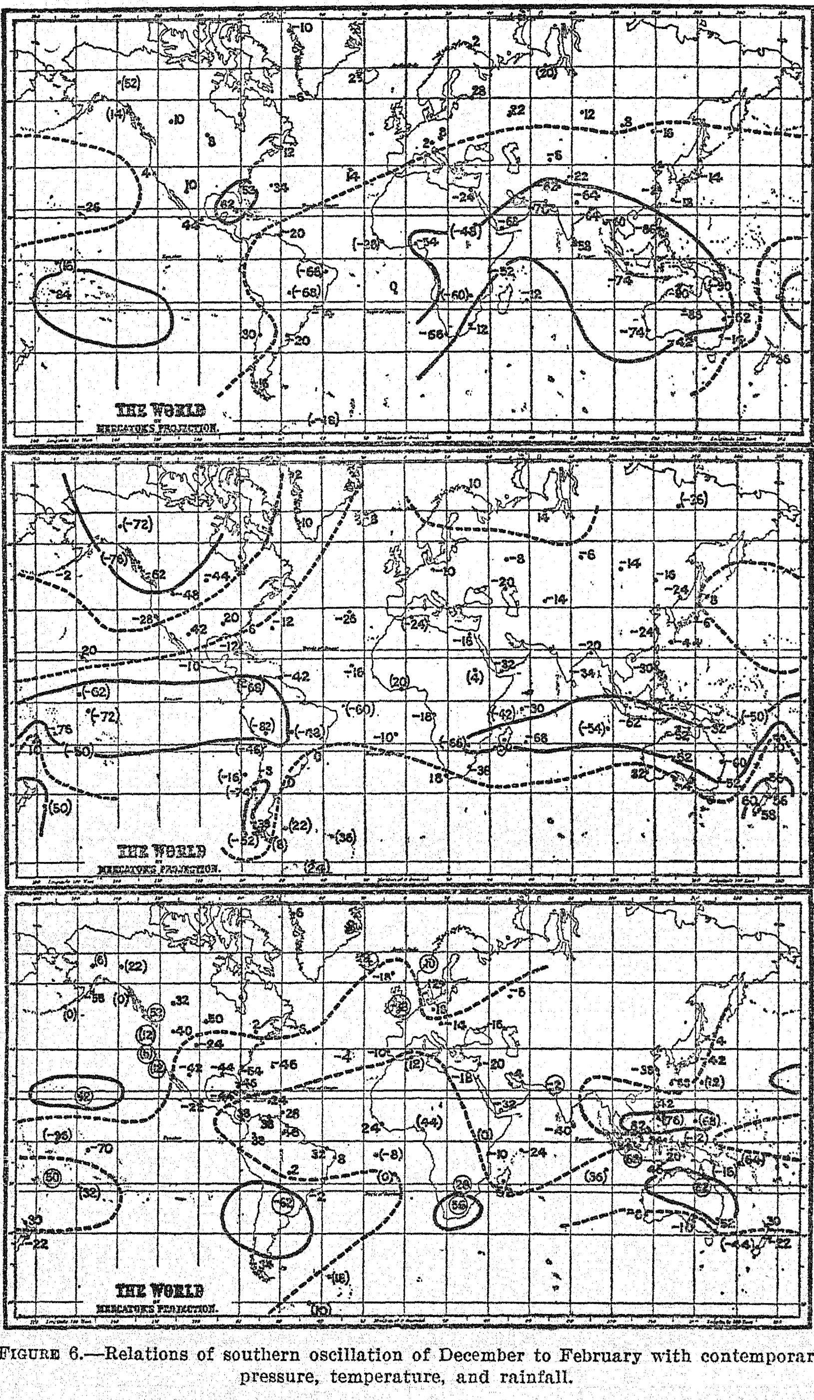


FIGURE 6.—Relations of southern oscillation of December to February with contemporary pressure, temperature, and rainfall.

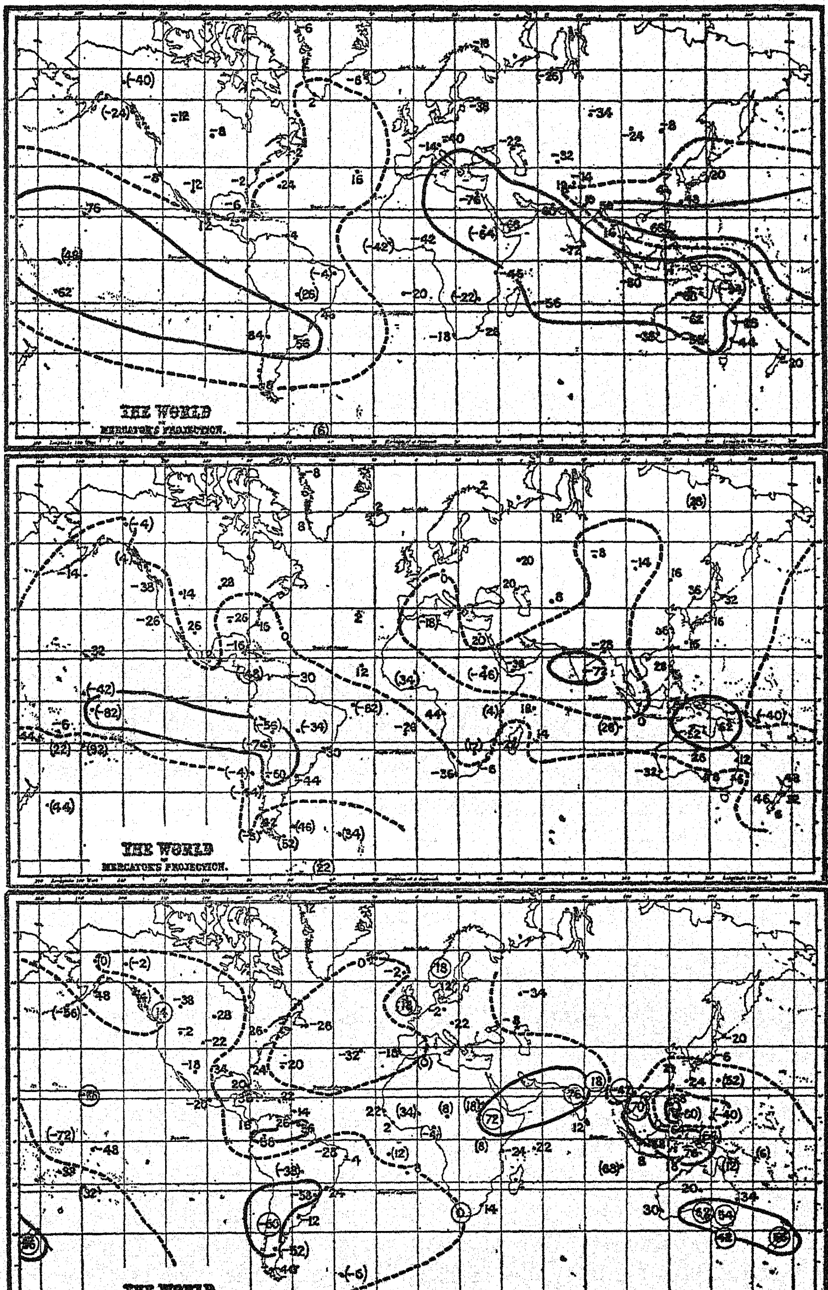


FIGURE 7.—Relations of southern oscillation of June to August with contemporary pressure, temperature, and rainfall.

fluctuation is called positive when pressure is high in the southern Pacific and low in the Indian Ocean, and temperature is mostly low in the Tropics; but the economic importance is in connection with rainfall, for the fluctuation has a correlation coefficient of over 0.8 with the summer rainfall of northeast Australia, over 0.7 with the monsoon rainfall of India and with the Nile floods, 0.6 with the rainfall of large areas in South America, and over 0.5 with that of a region in South Africa.

A surprising fact comes out on comparing the numerical series giving the characteristics of the summer and winter values of this fluctuation, the control of the southern winter on the succeeding summer being expressed by a coefficient of 0.82, the corresponding data being plotted together in figure 8; but the relationship with the previous summer is only 0.2. The immediate effect of this is

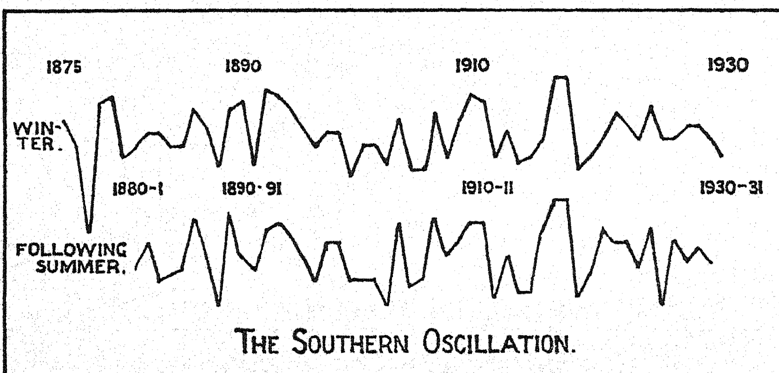


FIGURE 8.—Forecast of December to February from previous June to August.

that numerical values of the winter oscillation give us a means of predicting 3 months in advance, at any rate approximately, the summer values of the oscillation and therefore of the pressure, temperature, and rainfall associated with them. In figure 9 are the relationships of the values of the pressure, temperature, and rainfall of December to February, with the numbers indicating the fluctuation of the previous June to August. These express relationships which have held for about 50 years, and show that we have arrived, not at a mathematical figment, but at a physical reality of commercial value.

These methods of prediction can be improved on by study of the relationships of individual areas. For example, the coefficient of 0.64 of rainfall of northeast Australia with the oscillation of the previous winter becomes 0.79, when we base it on previous pressure at Honolulu, Port Darwin, and South America; a comparison of the

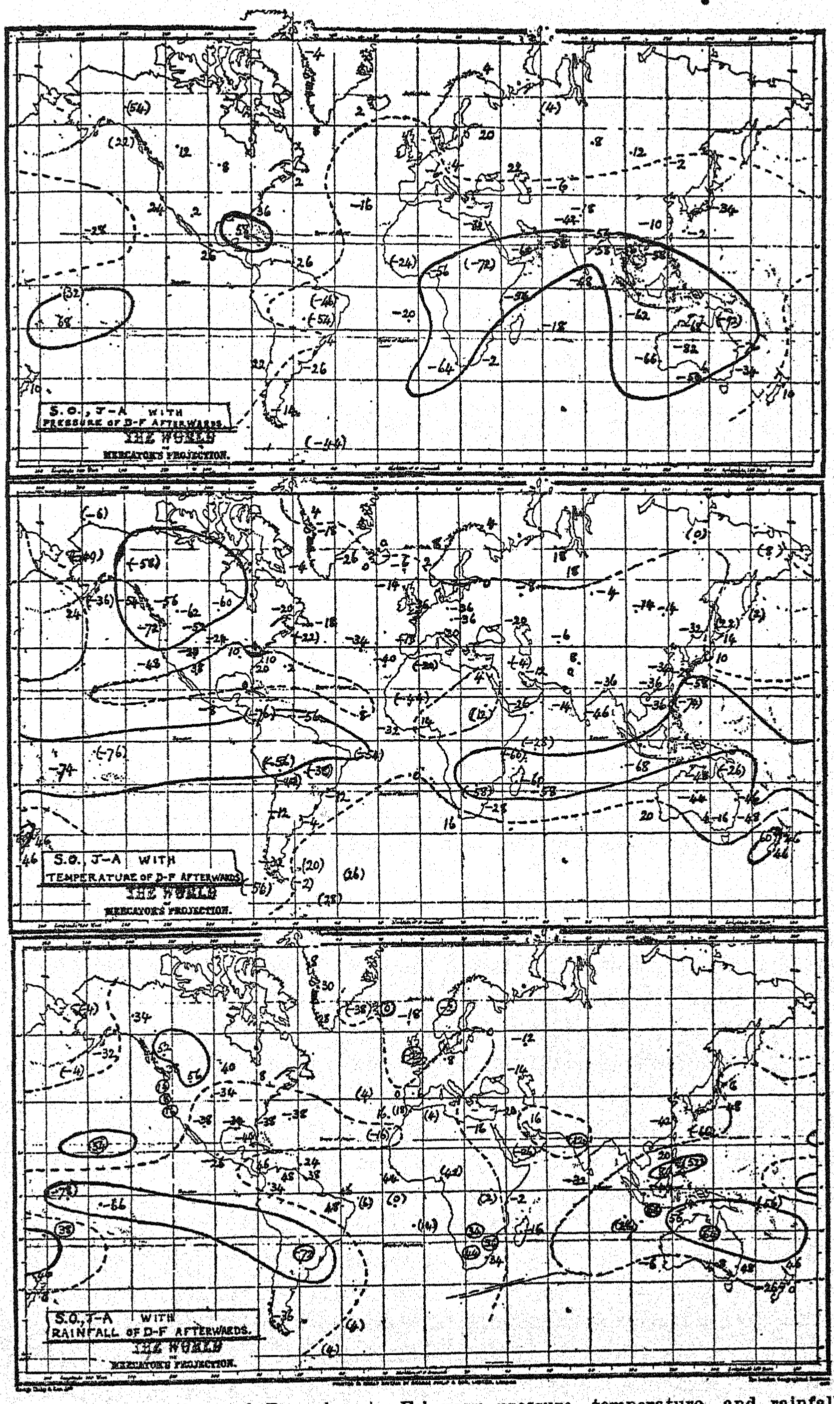


FIGURE 9.—Indications of December to February pressure, temperature, and rainfall from southern oscillation of previous June to August.

actual rainfall with that given by the formula is shown in figure 10. Similarly, the 0.56 of South Africa becomes 0.72. But a certain amount of the improvement effected in this way by selecting the biggest factors is bound to be fictitious, even when there appear to be adequate independent reasons for thinking that the relationships are real; and, if this precaution is ignored, the more promising the formula, as indicated by the closeness of its apparent relationship, the greater is the likelihood of disappointment.

It must be admitted that a real control of 0.7 by previous conditions is about as good as is now available for forecasting, and the difference between the actual and the forecasted amounts will still be considerable; so predictions can only be issued with restraint if public confidence is to be won. The natural consequence is silence, except when the indications are markedly favorable or unfavorable: In a race with 30 starters a conspicuously good horse may, without

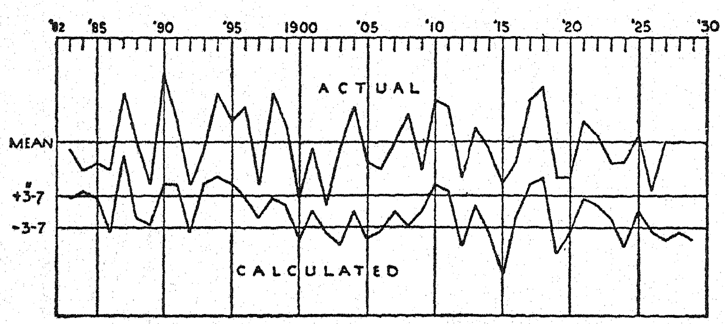


FIGURE 10.—Northeast Australian rainfall, October to April.

undue risk, be backed to come in within the foremost 6, and we may feel confident that a thoroughly bad animal will be in the last 6; but it would be unwise to hazard much on the likelihood that a commonplace individual will finish among the central 6. It may at first sight seem a confession of weakness to issue no forecast when conditions appear roughly normal; but it is better to admit your limitations, and only speak when you can do so with some safety, than to issue predictions when they are little more than guesses.

The objection is sometimes raised that though a foreshadowing of abundant or scanty rain over a region may be right four times out of five, owing to local variations the predictions will not be so successful when applied to a particular farm; and it must be admitted that this criticism is valid. But in England, as I learn from Sir John Russell, there are modifications of treatment and manuring that are appropriate before wet seasons and others before dry; in South Africa, in hilly country, the upper levels are better for cultivation in

wet years and the lower ones in dry years; in India, if the rains fail, cotton and millets will grow though the ordinary crops may perish. We may hope that, when our methods have improved, the predictions when applied to a particular farm will be right at least three times in 5 years; and if they are consistently acted upon, they will prove of material value in the long run.

Of further applications of these methods some are worthy of a passing notice. For Siam, whose summer rain has a coefficient of 0.7 with the contemporary southern oscillation, a former Indian colleague has worked out a foreshadowing formula with a relationship of 0.8. And at length China, which has suffered terribly from floods as well as droughts, is receiving attention. A graduate from Shanghai, now working in London, finds that the Yangtse valley and three areas along the coast have enough data for a preliminary investigation, and has worked out formulae for prediction with coefficients between 0.6 and 0.7. Mention should also be made of the researches of Okada in connection with the rice crop of Japan.

Let us now turn from the academic to the practical, and see how far these theoretical methods justify themselves in actual experience. I believe that the earliest regular seasonal forecasts based on meteorological instead of astrological data were those of the Indian monsoon of June to September, started half a century ago in India by H. F. Blanford, and depending mainly for their success on the ill-effect upon the monsoon of excessive winter or spring snowfall in the Himalayas; finally, however, he made the big generalization that droughts might be associated with unusually high pressure over a great part of Asia, at Mauritius and in Australia. Eliot continued the monsoon forecasts from 1887 to 1903, but data in those days were scanty; he attempted far too much detail, his mode of expression was somewhat pontifical, and the newspapers became sarcastic; so latterly he obtained immunity from criticism by printing the forecasts as confidential documents. The gradual introduction of statistical methods in India has undoubtedly led to improvement; but, as we have seen, it is much easier to predict the rainfall of December to February than that of June to September, and the length of the series of Indian data is not yet great enough to give complete reliability. After careful scrutiny I estimate that of the forecasts issued before the monsoon periods from 1905 to 1932 two-thirds were correct; but I consider that this is not good enough and that we have been too ambitious. Also while the approximate prediction formula of 1908 has stood the test of time with credit, the later ones of 1924 for northwest India and the Peninsula separately, although certainly better in theory, have not, in the short period of trial, proved so

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successful. The contrast between the working of the formulae before and after their date of preparation will be seen in figure 11.

Happily in Southern Rhodesia, which in 1922 adopted statistical methods similar to those of India with only 24 years of data to work upon, the results have been eminently satisfactory. Out of 11 years since publication was begun, there have been 8 in which a departure of over 3 inches was given by the formula, and in 7 of these the character was correctly indicated (fig. 12).

At Batavia the efficient Dutch observatory under Braak started in 1909 to issue forecasts founded on the simple rule that low pressure from January to June was followed by abundance of rain from July to December. The rule demanded a more complete persistence of pressure than actually prevails, and in 1927 Berlage adopted a formula based on three local conditions, together with data of the rare rains of northern Peru: this gives, on paper, a relationship of over 0.8.

In Australia calamitous failures in the rains have long demanded forecasts, and these led to the production of weather cycles, which broke down so frequently that their use was discarded. In spite of this experience, however, Hunt, the Commonwealth Meteorologist, put forward in 1929 a theory of a 4-year period, based on the cooling effect of the wide-spread growth of luxuriant vegetation produced by the rainfall in areas that were parched. I believe that the theory has not been adopted officially.

When we turn from the tropical and subtropical to the temperate regions, where the persistence of conditions is in general conspicuously smaller, we must expect greater difficulties in making long-range forecasts. In America the relations of weather and crops have probably been worked out more scientifically than in any other country, so that the commercial value of reliable predicting has long been recognized; and not only by farmers, but by those interested in water supply, in power schemes, in transport, and in commerce generally. Thus one of the Californian hydroelectric companies makes its own forecasts, because it may spend $4,000,000 more for crude oil in a dry than in a wet year. In a country of exuberant vitality it is not surprising that many efforts should have been made to provide for the general demand. In an article in 1927, by C. F. Brooks, we read that in the absence of forecasts "western farmers have paid a 'rainmaker' thousands of dollars at a time" actually to produce rain; that during the previous 10 years "well over 50 long-rangers of greater or lesser repute have been publishing and, in a great many cases, accepting money for worthless or damaging forecasts." As in Europe, they have predictions based on occurrences on critical days, such as Candlemas or St. Swithin's, as well

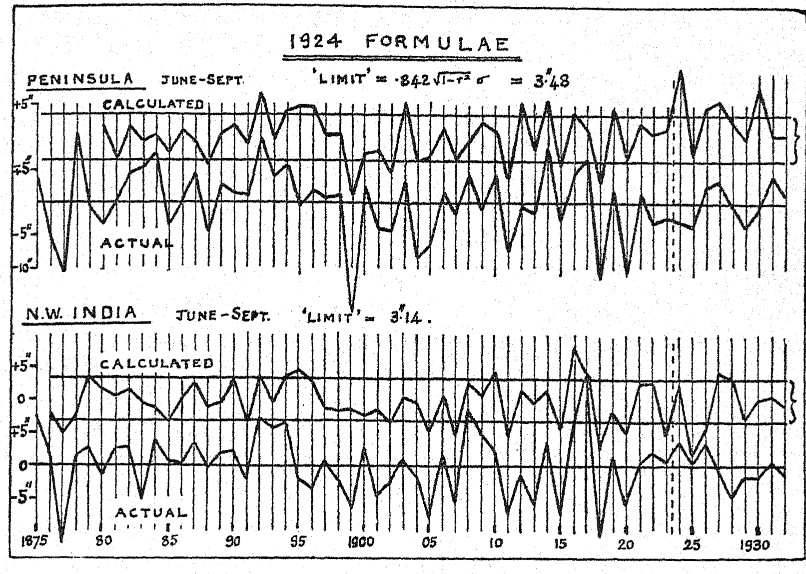

FIGURE 11.—Calculated and actual Indian rainfall.

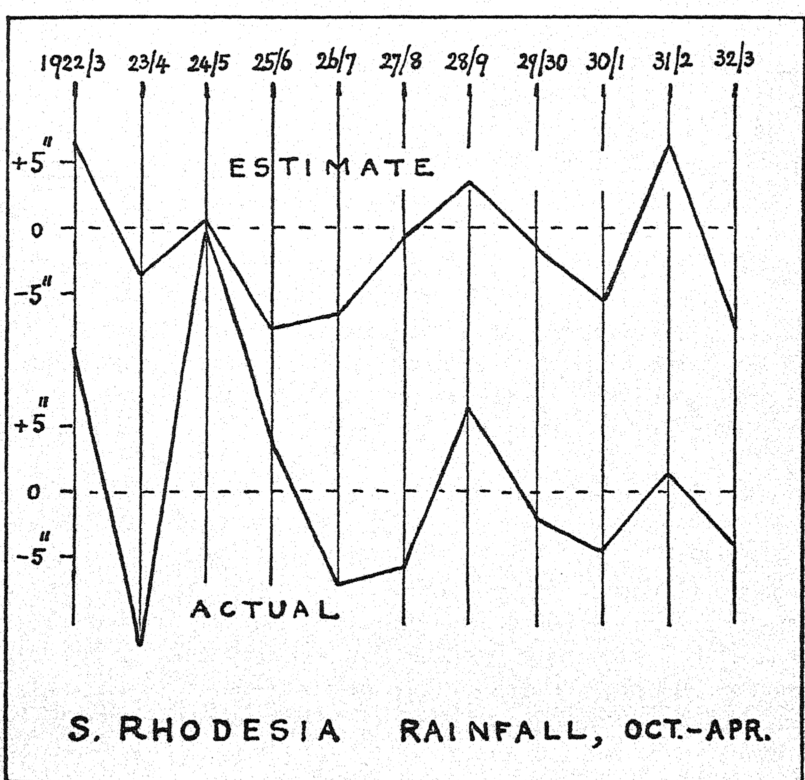

FIGURE 12.

as on the doings of animals and birds. Thus Brooks quotes from an almanac of 1870: "When you see 13 geese walking injun file and toeing in you can deliberately bet yure last surviving dollar on a hard winter, and grate fluktuousness during the next seazon in the price of cowhide boots."

Undeterred by the difficulties, G. F. McEwen, of the Scripps Institution of Oceanography in California, has for some time been forecasting rainfall by empirical methods, and at first attained considerable success, largely on the basis of a short series of ocean temperatures. These, however, as he has recognized, have not of late made good their early promise; and he is driven to using sun-spot numbers, a cycle of 5 or 6 years, and a complex method of smoothing in the hope of attaining reliability.

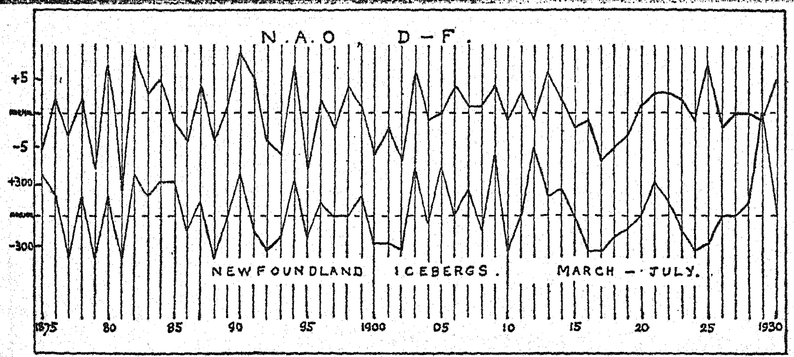

FIGURE 13.—Atlantic icebergs and the previous oscillation.

A less difficult task confronts the International Ice Patrol Service of the United States in their desire to obtain advance information of the amount of Arctic ice drifting into the western North Atlantic. I do not know what progress has been made, but the dependence on the previous North Atlantic oscillation, with which there is a coefficient of 0.60, would appear to suggest a useful starting-point (fig. 13).

In Europe the only seasonal forecasts known to me that have a scientific foundation, and have been made for a number of years, are those of Sweden and Russia. In Sweden Wallén has for 18 years made predictions for rainfall and for the height of water. Regarding rainfall, he smooths by taking the sums of consecutive 12 months; and then, assuming that the nature of the fluctuations so disclosed will not change suddenly, he forecasts that the total rainfall of some definite period, usually 6 months or a year, will be greater, or less, than it was in the previous year. Now a moment's

thought will make it clear that a man will in the long run be right three times out of four if, when last year's rain was in defect, he predicts an increase, or if it was in excess he forecasts a diminution. So I think it is not unfair to say that success under the Swedish conditions begins at 75 percent. The success actually attained is 82 percent, which is encouraging; and the success in dealing with water levels is phenomenally great, being slightly over 90 percent.

The seasonal conditions of Russia, which are not very closely related with those of the North Atlantic, have been carefully examined by W. Wiese. In 1923 the Hydrometeorological Office of Leningrad started publishing forecasts of ice in the Barents Sea, and out of 17 monthly forecasts of which I have information 15 were approximately correct. Predictions of the rainfall of April and May in central and east Russia were initiated at the same time, and all the first 4 years they were approximately correct; the biggest difference between the actual and forecasted amounts was only 20 percent.

No account of European activity in this department could ignore the enterprise of Prussia 4 years ago in creating at Frankfort a. M. a post for research into long-period forecasting. Dr. Franz Baur has for the present wisely limited his activity to the issue of a forecast of 10 days; it would be impossible to expect results under these conditions which are as accurate as those of daily weather work, but I am informed that their standard fully demonstrates the trustworthiness of the principles employed. It is only by experiments of this kind that satisfactory methods of prediction can be developed.

We may now pass to the consideration of improvements in our methods, and the fundamental question at once arises—what is the physical cause of seasonal fluctuations? We should naturally look for it in variations in the energy received from the sun, and it is surprising that an increase in solar activity as measured by sun spots produces a slight decrease in the circulations in the North Atlantic and the North Pacific. In the southern fluctuation the tendency of numerous spots is to produce positive values, but even there the biggest seasonal correlation coefficient is only 0.26, which is much too small to provide the explanation that we seek. Moreover, it probably arises because a positive fluctuation is associated with low temperatures between latitudes 40° N. and 40° S., and these are linked with an increase in sun spots.

In order to verify that the daily pressures are not produced by short-lived emanations from the sun tabulations of the relationships between daily and weekly, as well as the monthly and seasonal, values at distant places have been made; for if the daily values over the

earth are controlled from outside there will be close parallelism between these daily and weekly pressures. It was found that between 31 daily contemporary pressures at Honolulu and Batavia the coefficient was −0.12, which is negligible; between 39 weekly ones it was +0.10; between 47 monthly June pressures it was −0.12; and between the pressures of 47 three-monthly seasons of June to August it was −0.46. Between Samoa and Batavia December pressures the coefficient was −0.38, and for the season December to February it was −0.60. Thus it is between the characteristics that persist over months, not over days or weeks, that relationships exist.

Being forced off short-lived phenomena we search for an explanation in terms of slowly changing features, such as ocean temperatures; and the big variations from year to year in the amount of pack ice in the antarctic seas forces itself on our attention. But here the reports of 12 years from the South Orkneys yield a relationship of only 0.32 with the southern fluctuation, instead of about 0.9, as we should want in a prime cause; and the variations at the South Orkneys come after rather than before those of the southern oscillation. The biggest ocean region is the Pacific, and as an index of its seasonal water temperature we may use the corresponding air temperature of Samoa, which shows a greater persistence than any factor in the world as yet examined; the relationship between its summer and autumn values is as large as 0.94. But unluckily the correlation coefficients show clearly that it is mainly the southern fluctuation in winter that controls the Samoa temperature. Thus, a short-cut to the explanation of our fundamental problems seems as far away as ever. Our three big fluctuations each form a system of changes which are apparently held together by meteorological links; and there is, in my opinion, as yet no satisfactory proof of any free periods associated with them.

Let us now consider in what direction new developments seem likely. A moment's reflection will convince us that in view of the variations of rainfall over large areas, such as Brazil and Central Africa, which are scarcely affected by the three big fluctuations, there must be others, some of which are probably on a big scale. For example, we should, on the analogy of the northern oceans, expect a fluctuation of pressure between the antarctic low-pressure belt and the high-pressure belt of 30° S. We are at once reminded of the marked opposition which Simpson found during the short period of 4 years for which data were available between pressure at McMurdo Sound and that in a belt round the earth extending from about 25° S. to about 50° S. All students of this subject have found it natural to regard the fluctuations in the amount of pack ice in the antarctic seas as likely to control sea and therefore air temperatures over

large regions, and the most southern station from which as many as 25 years of data are forthcoming is the South Orkneys. Its winter pressure does show the opposition that we should expect with that of Australia, but not with the high-pressure region of South America or Mauritius; so that it gives little support to the view that there is a general pressure oscillation between the low- and the high-pressure belts of the Southern Hemisphere. On the other hand, the air temperature at the South Orkneys may be regarded as an index of the sea temperature; and as the ocean current through the Drake Passage would take about a year to reach South Africa, we are not astonished at the relationship of 0.56 between the South Orkneys air temperature in winter and that of the next winter at Cape Town.

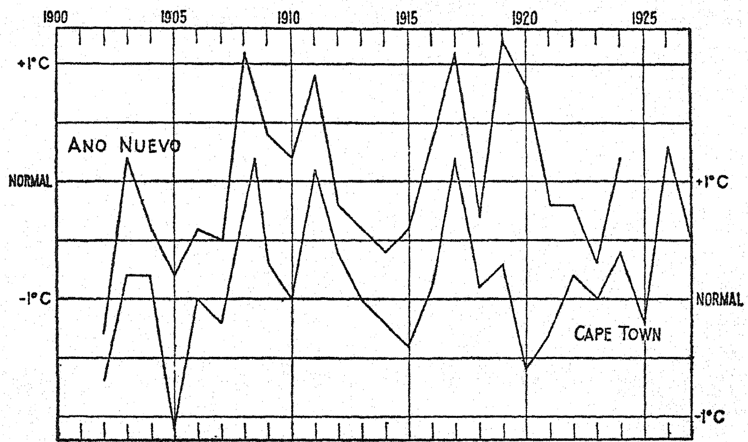

FIGURE 14.—Departures from normal of Ano Nuevo temperature, June to August, and of Cape Town temperature, June to August, of the following year.

This is not, however, as close as the corresponding relationship of 0.84 shown in figure 14 between the winter temperature at New Year Island at the extreme southeast of South America, and that at Cape Town a year later. The far greater influence of New Year Island is interesting, since between Cape Horn and the South Orkneys there runs ENE. a line which the recent *Discovery* expedition calls the Antarctic Convergence; here the cold antarctic water meets the northern warmer water and dives under it. So while the current flowing past New Year Island can after a year approach South Africa, that from the South Orkneys is cut off by a barrier.

If I may summarize these remarks, I would say that although seasonal foreshadowing is still very imperfect it has come to stay; for situations will arise from time to time, as they did in India in 1905, in which it can be foreseen with practical certainty that rains will

fail and a warning will then be of great value. But those who prepare formulas by the selection, based merely on the closeness of their apparent relationship, of a few out of many factors must remember that they cannot expect the value of all these factors to be maintained; and if they have a forecasting formula which on paper works out with a coefficient of, say, 0.75, they must realize that this is in reality probably not more than 0.6, or in some cases even 0.4. And I would plead for a much severer standard in handling questions of periodicity. If these views are right, no anticipations should be published except on the strongest evidence of excess or defect until the experience of 15 or 20 years has justified a less cautious policy.

Finally I would express the hope that the subject may, by its potential value to the race, and by the many-sided nature of its interests, enlist the services of some of my hearers who are qualified to unravel some of its intricacies.

THE SUN'S PLACE AMONG THE STARS[1]

By Walter S. Adams
Mount Wilson Observatory of the Carnegie Institution of Washington

[With 5 plates]

In previous lectures in this series you have had described to you the many skillful and important investigations that have given us such extensive knowledge of the sun as a source of light and heat, of its composition, physical nature, and characteristics, and of the far-flung gravitational attraction by which the sun holds the planets in their courses. I should like to consider with you the sun in its relation to the stars, how it compares in size and brightness and mass with the vast number of other suns by which it is surrounded, and what from analogy and comparison with the stars we may reasonably expect its future life history to be.

It will perhaps be of interest at the outset to interpret our subject literally and to define according to the best of our knowledge the geographical location of the sun among the stars. The stars in the observable universe are grouped into systems scattered like islands throughout space and separated by enormous distances, which light requires millions of years to traverse. These systems of stars, the extra-galactic nebulae of the astronomer (pl. 1, fig. 1), extend out to the limits of the largest telescopes and, generally speaking, seem to be distributed uniformly; that is, the same volume of space in all directions and at all distances contains about the same number of stellar systems or nebulae. Occasionally clusters of nebulae are found in which hundreds of these objects appear upon a single photograph, but from a statistical point of view these clusters do not affect the uniformity of the distribution seriously. The space between the nebulae seems to be singularly free from matter; probably some traces of gas and of cosmic dust are present here and there, but observations of the light of the most distant nebulae show that even throughout these immense distances there can be but very little obscuring material.

[1] The fourth Arthur lecture, delivered at the Smithsonian Institution on Dec. 18, 1934.

The sun is situated within one of these systems of stars, which is known as the galaxy. Like most other well-developed stellar systems containing great numbers of stars it is not round but lens-shaped in form, with a length some 5 to 10 times its thickness (fig. 1). As we look out into the galaxy from our position inside, the circle of the Milky Way forms the largest dimension of our lens, or the equator of our galaxy, and we see a vast number of stars because we look through a great depth throughout which they are scattered. At right angles to the galaxy where the thickness is much less the number of stars is also much less. Our system of stars is probably not definitely bounded but fades off more or less irregularly into empty space, and included within it are not only stars but clouds of gas, cosmic dust, star clusters, star clouds, and the numerous other forms in which the material that builds the stars can occur. Especially in the direction of the center of the galaxy in the constellation of Sagittarius are there great masses of dark cosmic clouds, nebulous stars, and star clouds that point to a marked concentration of matter in this region (pl. 2).

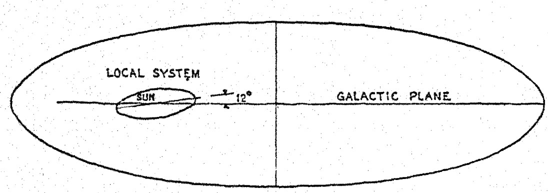

FIGURE 1.—Diagram of our stellar system. The smaller local system about our sun is also indicated.

Our galaxy is about 100,000 light-years along its greatest diameter, and the sun is situated about halfway between the center and edge, or some 25,000 or 30,000 light-years from the center, and slightly north of the equatorial plane. As a result of modern investigations it is certain that the entire galaxy is in rotation about its center or, more accurately, that the stars are in revolution about the center of gravity of the system just as the planets are in revolution about the sun. The stars nearest the center revolve most rapidly and in the shortest period. The velocity of revolution of the sun about the center of the galaxy is about 165 miles a second, and it would require some 225 million years for the sun to complete one entire revolution.

Scattered throughout this great volume of space are the stars that constitute our system, variously estimated at from 100 to 200 billion in number. The difficulty in determining the number of the stars arises from the necessity for making the proper allowance for the great proportion of faint small stars, which certainly outnumber greatly the more luminous stars in our galaxy. These small stars, the dwarfs of our system, which we shall have occasion to consider later, become so faint at great distances that they are quite beyond the reach of the largest telescopes. Accordingly such stars can be

observed only in a limited volume of space around the sun, and it is only by assuming that their frequency throughout the whole galaxy approximates that in this small sample volume that any estimate can be made of their total number.

If we sum up our conclusions, therefore, we find that our sun is one of many billions of stars forming a flattened system similar to many other systems scattered throughout the observable region of space. It was long thought that the size of our system was considerably greater than that of the nearer extra-galactic nebulae which can be studied in detail, but recent observations have tended both to reduce the earlier estimates of the size of our galaxy and to increase the size of the outer stellar systems. As a result the size of our system of stars is now believed to be quite comparable with that of the Andromeda nebula (pl. 1, fig. 2), one of the nearest and best observable of the outer nebulae, which has a distance of about 900,000 light-years.

The total mass of our galaxy, including not only the stars but all the other material contained within it, is estimated at about 160 billion times the mass of our sun. This value is derived from the rotation of the galaxy. So large a figure gives an impression of considerable average density, but the size of the galaxy is so great that the actual density is extremely small. In the vicinity of the sun the average separation of even the faintest dwarf stars is of the order of 10 light-years. Throughout the observable universe the average density is, of course, very much lower, and recent investigations give a value corresponding to that of 15 grains of matter distributed uniformly throughout a volume of space 1,000 times the size of the earth.

When we begin to consider the place of the sun among the stars as a physical body and attempt to compare it with other stars we naturally start with its brightness. We know that the sun is very bright and that the stars are faint, but we also know that the stars are very far away. A natural question to ask is how the sun would compare in brightness with the average stars of the night sky if it were removed to the average distance of a star. The answer is comparatively simple. Among the stars, just as on the earth, the so-called "inverse-square law" of light and heat holds accurately in the absence of any obscuring material. This means that if we double the distance we divide by four the amount of light and heat we receive from an object, whether that object be a candle, the sun, or a star. If the sun were 10 times as far away from us as it is we should receive only one hundredth part of the present amount of light. Now the average distance of the sun is about 92,000,000 miles, and the distance of an average nearby star is at least 33 light-years

where a light-year is the distance which light travels in a year at the rate of 186,000 miles a second. Roughly a light-year is 6,000,000 million miles. If we carry through the arithmetic we find that at a distance of 33 light-years the sun, although still visible, would be among the fainter of the stars seen with the naked eye, and only about three times as bright as the faintest star that can be seen with the eye under the most favorable conditions. The great majority of the naked-eye stars are much farther away than the 33 light-years which we have assumed, so that as compared with these stars our sun is a relatively insignificant body.

This result shows us at once that the stars differ greatly from one another in the amount of light they give out, or, in other words, in their luminosity or candlepower. If all the stars had the same luminosity their brightness as we see them would depend solely upon their distance, but since this is not the case both distance and luminosity are involved. The inverse-square law, however, at once gives us a simple relationship between apparent brightness, intrinsic brightness or luminosity, and distance, and this relationship forms the basis of all studies of the distribution of stars according to their true brightness. Since this relationship is a simple equation between three quantities, we can always find the third quantity when the other two are known. But the apparent brightness or magnitude of a star may be assumed to be known: it is obtained from direct observation, and existing catalogs list hundreds of thousands of stars with accurately measured apparent magnitudes. So all we need to solve our equation is to know either the distance, in which case we can determine the luminosity directly, or the luminosity, in which case we can determine the distance.

The first and for many years the only way in which the luminosity of a star could be obtained was from a previous knowledge of its distance. Naturally the earliest method of measuring stellar distances grew out of accurate measurements of position. If the position of a star with reference to the faint stars in the background of the sky can be measured with great accuracy at a certain time, and again 6 months later when the earth is on the opposite side of its orbit around the sun, we have a base line of about 185,000,000 miles by which to measure its distance. As seen from the ends of this line the star should be slightly displaced with reference to the fainter stars in the background which are vastly more distant. If this angle can be measured, it is a simple matter, since the length of the base line is known, to calculate the distance. The method is very similar to that used in ordinary surveying. The difficulty arises, however, that the stars are so far away that even with this great base line the angle to be measured is extremely small. In the case of

but a single star does it amount to as much as 1″ of arc, and for the vast majority of stars it is less than one-tenth of this amount. A tenth of a second of arc with the telescopes usually employed for these investigations corresponds to about 0.00015 inch on the photographic plate; but such is the accuracy of the method and the skill of the observers that the distances of about 3,500 stars have been determined in this way. The measurements give directly a small angle, and one-half of this angle is called the parallax of the star. It corresponds to the angle subtended by the distance of the earth from the sun as seen from the star. The full moon as seen from the earth subtends an angle of about 1,900″ of arc.

This direct or trigonometric method of determining the distances of the stars is an extremely valuable one, and gives us our most

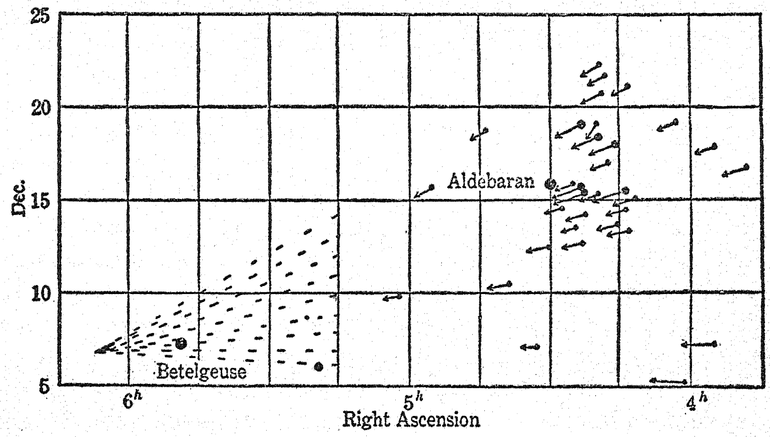

FIGURE 2.—A moving cluster of stars, the Hyades. (Lewis Boss.)

accurate knowledge regarding the distances of the stars in the neighborhood of the sun (pl. 3). Beyond distances of 300 or 400 light-years, however, its value in the case of individual stars falls off rapidly, since at these great distances the parallaxes are so small that the inherent error of measurement becomes a large fraction of the parallax, and finally equals or surpasses it. For the most distant stars, therefore, we must find other methods that do not depend upon direct measurements of position.

Several such methods are known, some of which give us with high accuracy not the distances of individual stars but the average distance of groups of stars of different brightness. Still others are applicable only to special classes such as double stars, or the interesting moving clusters in which the stars move together through the galaxy just as flocks of birds move together through the air (fig. 2). All these methods give parallaxes and distances directly,

and from these distances the luminosities can be calculated readily by the aid of the relationship which we have already considered connecting apparent brightness, distance, and luminosity.

There are, however, other methods that reverse the process, and, instead of deriving the distances directly and then the luminosities, we derive the luminosities directly and then the distances. A simple example will illustrate how such a method operates. Suppose we observe an incandescent lamp some distance away and can measure accurately the amount of light we receive from it, or its apparent brightness. If we know its distance we can determine its candlepower by the aid of the inverse square law as we have already seen. If, however, we do not know its distance but do know its candlepower, we can use the same law to determine the distance. So in the case of the stars the question at once arises whether there is any means for determining their candlepowers or luminosities directly.

There is a class of stars in the sky that vary in light in a peculiar way throughout a definite period. A careful study of stars of this class in star clouds where they are known to be at closely the same distance, and of others at known distances, has led to the establishment of a law connecting the luminosities of such stars with the length of period of their light-variations. This law is quantitative, so that the luminosity can be determined when the period of variation is known. Stars of this character have been recognized in the stellar systems of outer space, their periods of light-variation have been observed, and from these periods the luminosities of these stars have been derived. These in turn give us at once the distances of the nebulae of which they form a part—the only accurate means as yet devised for determining the distances of these enormously remote objects.

This method illustrates one of the direct ways in which stellar luminosities can be determined for stars of a certain class. Another method which has very wide applications depends upon the physical properties of stars, and a somewhat more detailed analysis will perhaps be of interest, not only because the method has been fruitful in its results, but also because it illustrates many of the principles used in modern astrophysical study.

The temperatures of the surfaces of stars have been measured by several different methods and are known with considerable accuracy. As we might expect they differ widely: some of the dull red stars have temperatures as low as 2,000° on the Centigrade scale, while many of the blue stars reach temperatures of 20,000° or more. The temperature of the surface of our sun is about 6,000° C. or nearly 11,000° on the Fahrenheit scale. One of the ways in which the

temperature of a star is very quickly recognized is from the analysis of its light into a spectrum. The distribution of the light of different colors throughout the spectrum, the presence or absence of certain lines, and many other features determine the temperature of the star rather definitely (pl. 4). So stars of the same spectral type have closely the same temperature. Now, it is a fact of observation that the masses of stars of the same spectral type do not differ very greatly. A factor of 10 would cover the vast majority of cases. We know this from a great variety of evidence, mainly from double stars for which the masses can be calculated accurately. On the other hand, we know that the luminosity or candlepower of stars shows enormous variations, stars of the same spectral type sometimes differing as much as hundreds of millions of times in the amount of light they give out.

Since the surface brightness, or the amount of light each unit of area gives out, is nearly the same for stars of the same temperature or spectral type the only explanation for the immense difference in luminosity is a great difference in size. In other words, the very luminous stars must be very large as compared with the fainter stars. Since the masses, however, do not differ very greatly, the brighter stars must be very much less dense than the fainter stars. We conclude, therefore, that many of the brighter stars in the sky must be enormous masses of gas of very low density, a conclusion fully borne out by measurements of diameter with Michelson's interferometer, which show the existence of great red stars as much as 200,000,000 miles in diameter, or more than 220 times the diameter of our sun. (Fig. 3.)

Such stars are recognized through a study of their spectrum. When a star gives out light, the atoms of the gases in its atmosphere are in an excited state and absorb light in the particular wave lengths that correspond to the spectrum lines of each element involved. So we get a pattern of lines of all the elements in the star's atmosphere. When the temperature of the star is low, we obtain the lines of what is called the neutral atom, the atom in its normal state, but if the temperature is high the atom is modified by having one or more of its electrons pulled off and becomes what we call ionized. Ionized atoms give rise to a different class of lines from neutral atoms, but in stars of ordinary temperature both sets of lines are usually present, some of the atoms being neutral and some ionized. In stars of low temperature the neutral lines are the stronger, in stars of high temperature the lines due to the ionized atom.

There is, however, another factor that favors the detachment of electrons from atoms, and this is the density of the star's atmosphere. If the density is low, there are fewer collisions and fewer

STAR DIAMETERS

MEASURES MADE BY PEASE WITH THE 20-FOOT MICHELSON INTERFEROMETER ATTACHED TO THE 100 INCH HOOKER TELESCOPE OF THE MOUNT WILSON OBSERVATORY

OTHER ASTRONOMICAL DISTANCES FOR COMPARISON

STAR		ANGULAR DIAMETER SECONDS OF ARC	DISTANCE IN LIGHT YEARS	LINEAR DIAMETER MILES
ANTARES	ALPHA SCORPII	0.″040	383.	430,000,000
ORBIT OF MARS				282,000,000
MIRA	OMICRON CETI	0.056	163.	260,000,000
BETELGEUSE	ALPHA ORIONIS	0.047	163.	218,000,000
ORBIT OF EARTH				186,000,000
SCHEAT	BETA PEGASI	0.021	251.	150,000,000
ALDEBARAN	ALPHA TAURI	0.020	53.	30,000,000
ARCTURUS	ALPHA BOOTIS	0.020	34.	20,000,000
SUN		1922.40	0.000016	866,000
EARTH				8,000

LIGHT YEAR = 5.89×10^{12} MILES

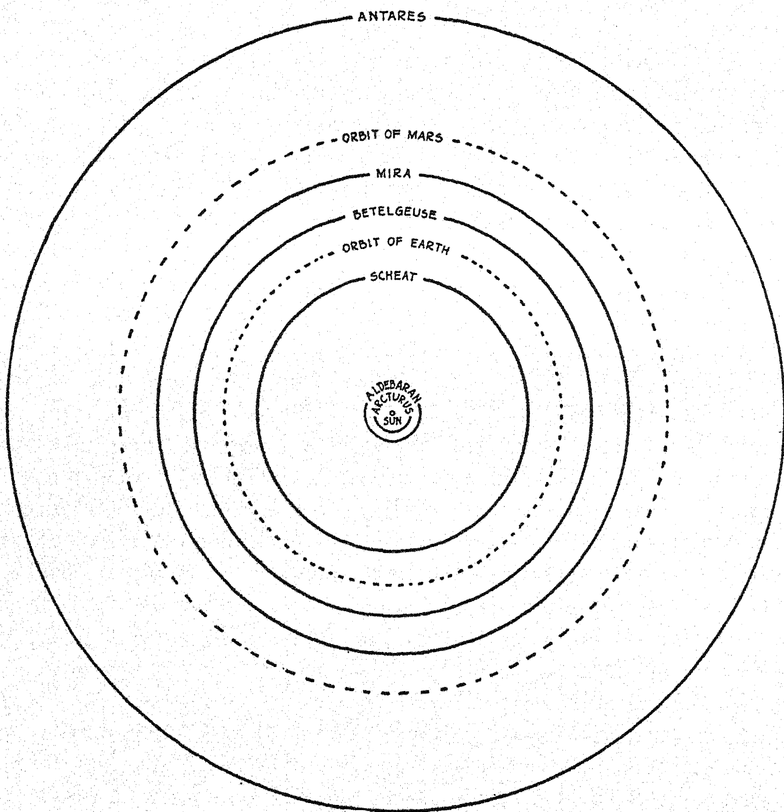

FIGURE 3.—Relative diameters of stars measured with the interferometer (Mount Wilson Observatory). The circles show the size of certain stars relative to the sun and to the orbits of the earth and Mars.

opportunities for a detached electron to reunite with an ionized atom. So we should expect the lines due to the ionized atoms to be strong in the spectra of stars of low density and weak in those of high density. This is just what observations show. An interesting application of this theory is found in the case of the spectrum of the sun's atmosphere (pl. 5, fig. 1). In the upper levels of the atmosphere the lines due to the ionized atoms are much stronger than at lower levels and this in spite of the fact that the temperature is lower. The lower density is the significant factor and leads to a great predominance of ionized atoms.

The application of these principles to the problem of determining the luminosities of stars is very simple. If we select two stars of the same spectral type whose distances have been measured by any one of the methods I have described, one of which has a high

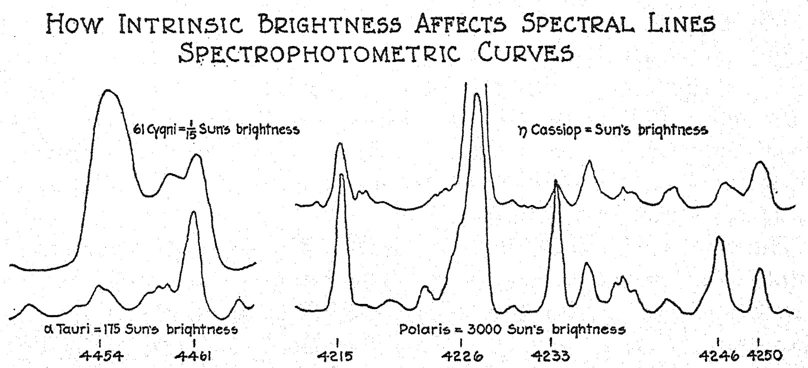

FIGURE 4.—In such tracings the height of the curve shows the intensity of the line.

luminosity and the other a low luminosity, we find the lines due to the ionized atom strong in the star of high luminosity because the density is low. By taking a sufficient number of stars of known distance and luminosity a correlation can be established between the intensities of ionized and neutral lines and the luminosity. Then in the case of any other star whose spectrum can be photographed it is merely necessary to measure the intensities of the selected lines and from the correlation-curve to read off the corresponding luminosity or absolute magnitude. In practice, pairs of neighboring lines are selected, one of which varies greatly with luminosity whereas the other is comparatively insensitive (pl. 5, fig. 2). In this way each spectrum of a star can be treated independently, and no absolute scale of intensities is necessary (fig. 4).

This is, very briefly, the method for deriving the luminosities of stars directly from their spectra. It is not so accurate as the method of angular measurement, the so-called "trigonometric method", for

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the stars in our immediate neighborhood, but for more distant stars it is superior since its accuracy is independent of the distance. Thus the two methods supplement each other in a most valuable way, and between the two we have acquired a knowledge of the luminosities and distances of about 6,000 individual stars.

When we begin to consider these results, we are led to some very interesting conclusions. In the first place, we find that the apparent brightness of a star as we see it may bear very little relationship to its real brightness or luminosity. Sirius, apparently the brightest star in the sky, is comparatively near us and gives out about 25 times as much light as our sun; Canopus, the second brightest star, is very far away and is almost certainly 10,000 times as luminous as the sun. Similarly Procyon, one of the brightest of the stars in the winter constellations, has 5 times the luminosity of our sun, while Rigel, the brightest star in Orion and of nearly the same apparent brightness as Procyon, gives out from 10,000 to 15,000 times as much light as the sun. The color of Rigel is bluish white, and its temperature is very high, so that its surface brightness is great. On the other hand, Betelgeuse, the other chief star in Orion, is red and has a low temperature and surface brightness; its diameter, however, is so enormous—over 200,000,000 miles—that its luminosity is nearly 1,500 times that of the sun.

The contrast between the luminosities of these giant stars and the faint dwarf stars is very great. The faintest star intrinsically of which we have any knowledge is the small companion of the nearest star in the sky, α Centauri. This star has a distance of 4.3 light-years, and its luminosity is 0.00006 of that of the sun. About a dozen stars are known the luminosity of which is less than 0.0001 part of that of the sun. So we find that among the stars already studied the luminosity or candlepower varies through a range of at least 200,000,000. This factor would be multiplied at least a thousandfold if we were to include the brightest of the new or temporary stars which suddenly blaze out and die away within a few days or weeks. The luminosities of some of these stars must be at least a million times that of our sun. So we find that the Biblical statement that "one star differs from another star in glory" is even more true of the stars as they really are than as they appeared to the eyes of the shepherds of Palestine.

A very remarkable result is found when the stars are grouped according to spectral type, or surface temperature, and their true luminosities. (Fig. 5.) The resulting diagram resembles a reversed 7, with the faint low-temperature stars lying along the stem of the figure and the bright low-temperature stars along the upper horizontal bar. Between the two there is a wide gap in which few or no

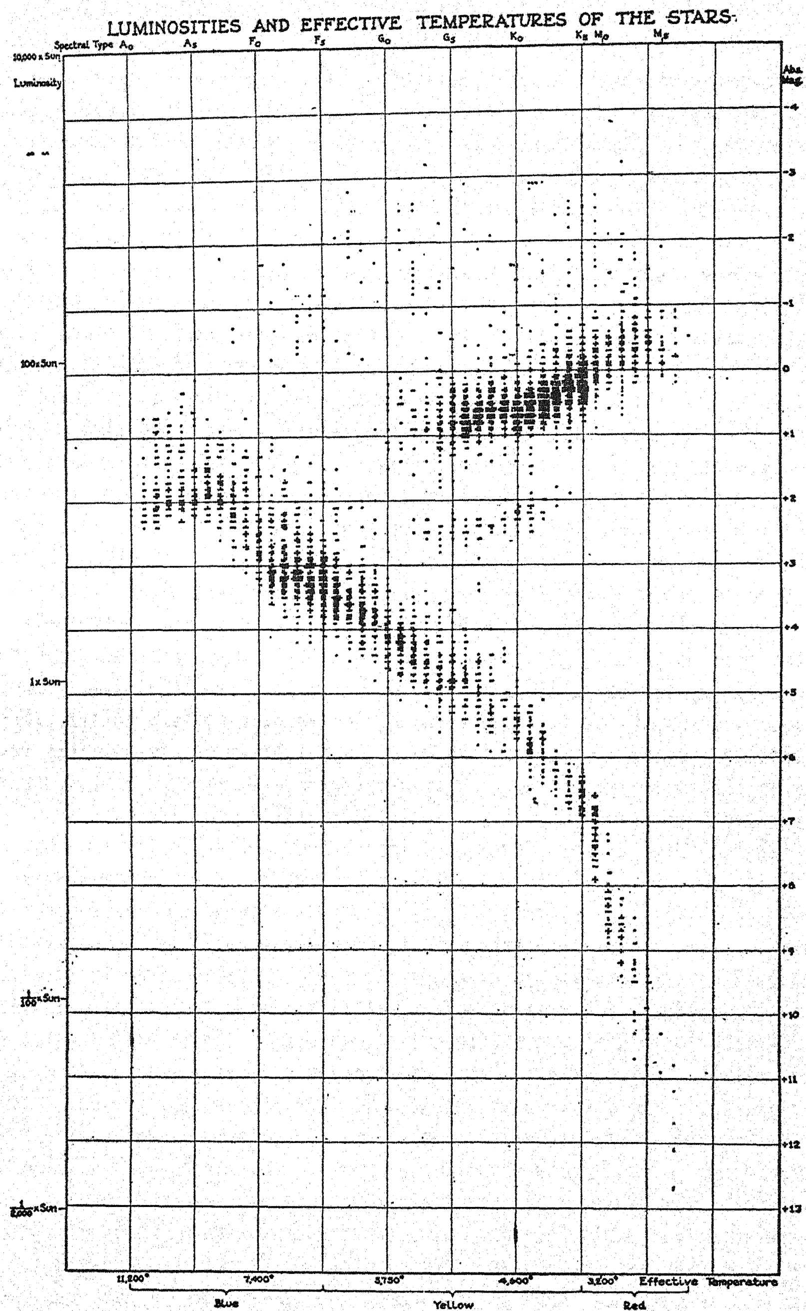


FIGURE 5.—Luminosities of 4,179 stars as derived by the spectroscopic method. Giants in the upper part of the diagram, dwarfs below. At the left the two sequences run together. (Mount Wilson Observatory.)

stars are found. These two classes of stars, to which the names "giants" and "dwarfs" have been given by astronomers, differ enormously in luminosity, the average low-temperature giant being at least 10,000 times as bright as the corresponding dwarf. This conclusion, originally drawn from trigonometric observations, is fully confirmed by the luminosities of nearly 4,200 stars recently determined by the spectroscopic method.

In general, stars may be divided according to luminosity into three classes, dwarfs, giants, and extremely bright stars that may be called supergiants. The separation between dwarfs and giants is widest among the stars of lowest temperature and becomes progressively less for stars of higher temperature, the dwarfs becoming brighter and the giants slightly fainter. Some stars of intermediate luminosity appear among these stars of increasing temperature, and the two chains of dwarfs and giants come together and may even cross among stars somewhat hotter than the sun with temperatures of 7,000° or 8,000° C. The supergiants, which include the most luminous stars in the sky, are found among stars of all temperatures and show a much greater range in luminosity than either the giants or the dwarfs of the same spectral type or temperature. They are especially numerous among the stars with temperatures slightly higher than that of the sun; in fact, stars of these types seem to contain few normal giants, the great majority being either dwarfs or stars of the supergiant class. Another interesting fact about the supergiants is that a large proportion of them vary in light, and it seems probable that such variation indicates a kind of instability that is associated with great size and high luminosity.

Perhaps the single most interesting result which comes from a study of the luminosities of stars is the remarkable tendency to group around definite values of brightness. This is especially marked in the case of giant stars, although very evident among the dwarfs. About 90 percent of giant stars with temperatures near 4,000° C. have the same luminosity within a range of twofold or threefold. In other words, most stars of a given temperature, like the bulbs of our electric lamps, are built to give out a definite number of candlepower and do not show the almost infinite range in luminosity we might so readily expect. The luminosity especially favored among the giant stars with temperatures less than our sun is about 100 to 150 times that of the sun. It does not change rapidly with decrease of temperature but on the whole increases slightly for the cooler giants. This is doubtless due to the larger size of these stars, the increase in the area which emits light more than counterbalancing the smaller amount given out by each unit of surface.

Among the dwarf stars, on the other hand, the change of luminosity with temperature is very marked. As the temperature decreases the luminosity decreases regularly and then drops abruptly as we reach the coolest stars. This is to be expected as the limits of visible radiation are reached and the light of the stars goes out. The dwarf stars are comparatively small, dense bodies, and the lower the temperature the less massive and the denser they are found to be. So there is no increase of size as among the giants to balance the effect of the decrease of surface brightness due to decreased temperature.

Our sun belongs to the sequence of dwarf stars that forms an unbroken chain between the faintest stars intrinsically of which we have any knowledge, stars that give out less than 0.0001 part the light of the sun, and the bright white stars with luminosities 50 or more times that of the sun. Within this sequence the sun agrees well with other stars of the same temperature: its luminosity seems to be slightly less than that of the average star of its type but well within the range that similar stars exhibit. In mass, spectral type, and many other characteristics the sun can be almost precisely matched by many of the stars which have already been observed. As a typical dwarf star, therefore, we can reason that the sun in its future history will pass through the evolutionary changes of similar stars in the main sequence to which it belongs. What these changes may be is very far from certain, for our theories of stellar evolution are still in a most indefinite state. The probabilities are that in the course of sufficient time the sun will radiate away much of its mass, will decrease in temperature and luminosity, and arrive at a condition similar to that of the faint red dwarf stars which are our most frequent neighbors. The time required for such processes, however, is almost incredibly long. It would take 40,000,000 million years for the sun to lose half its present mass through radiation, and it is quite possible that during a considerable part of that period the output of light and heat would not differ seriously from that at present. Every aspect of the study of the relationship of the sun to the stars as a physical body leads to a time-scale of enormous length, and it is clear that, whatever the future history of the earth, its destiny will be defined by limitations quite other than those set by a cold and inert sun.

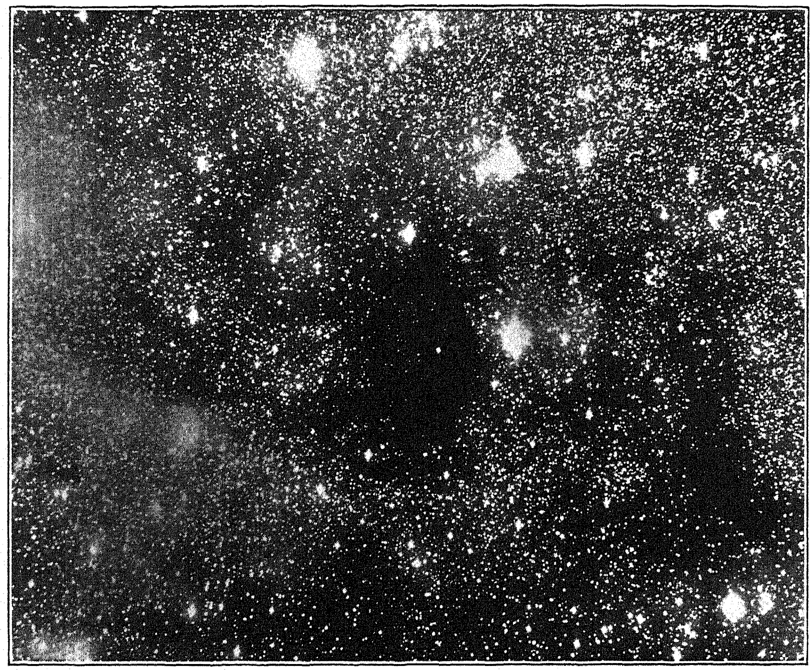
Mount Wilson Observatory.

1. AN EXTRA GALACTIC NEBULA, M 101.

Mount Wilson Observatory.

2. AN EXTERNAL GALAXY, THE ANDROMEDA NEBULA.

The reproduction is a mosaic from three photographs.

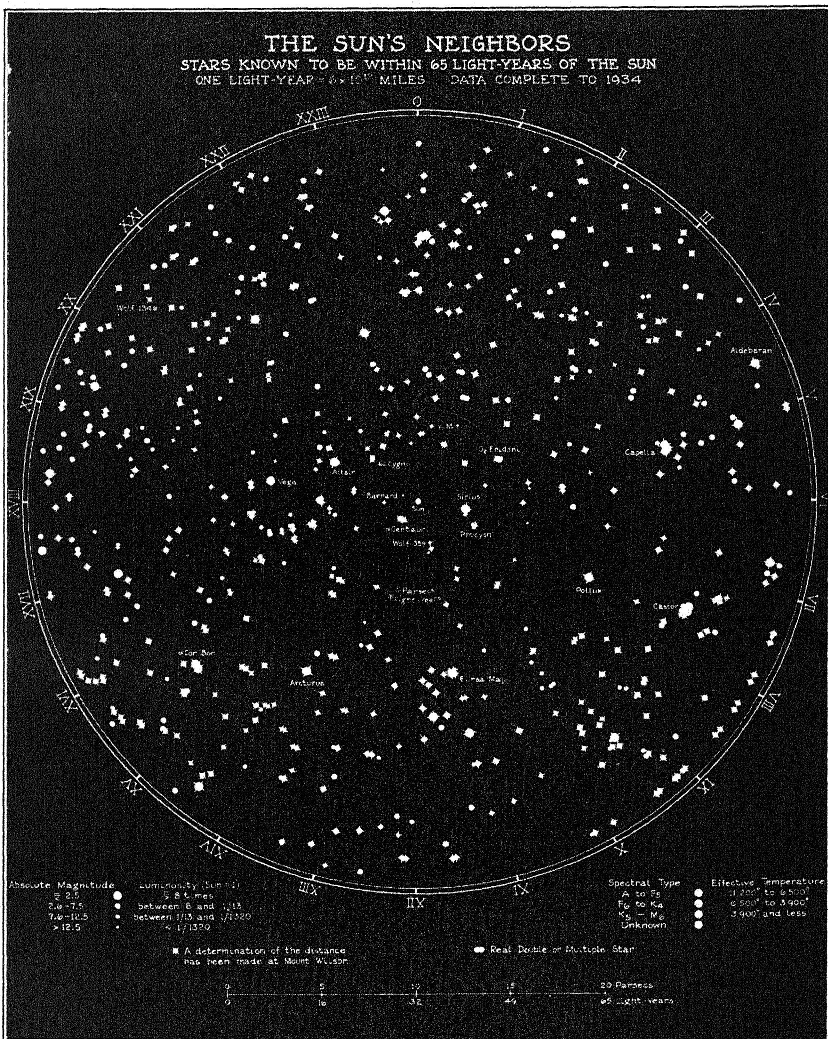


Barnard.

1. STAR CLOUDS AND DARK OBSCURING MATERIAL IN THE MILKY WAY.

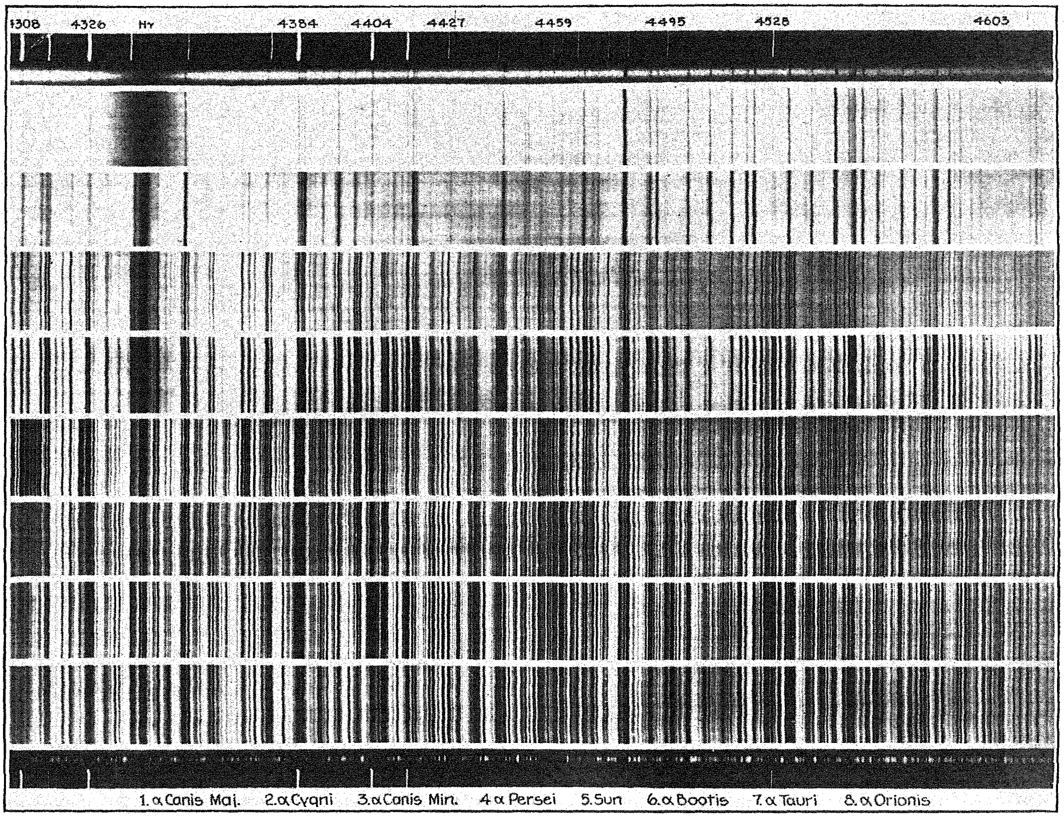
Mount Wilson Observatory.

2. BRIGHT AND DARK NEBULOSITIES IN THE CONSTELLATION OF SAGITTARIUS, M 8.



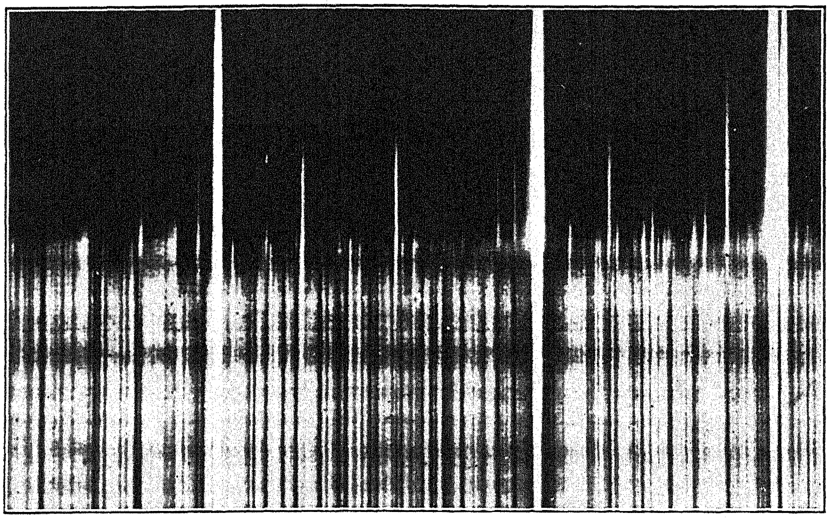
Mount Wilson Observatory.

STARS KNOWN TO BE WITHIN 65 LIGHT-YEARS OF THE SUN.



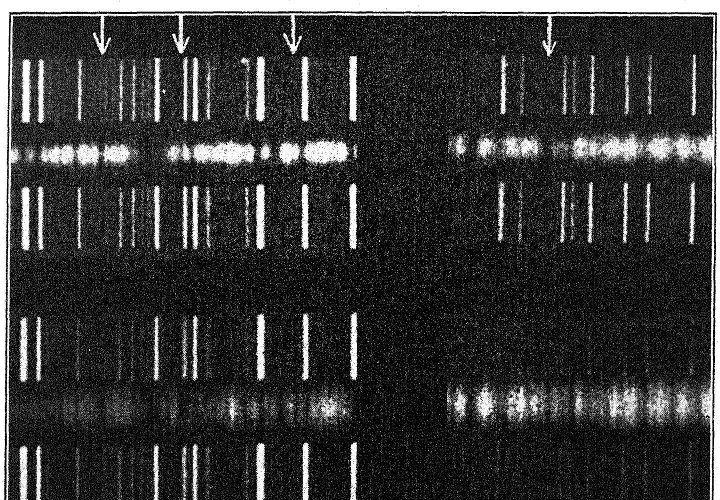
Mount Wilson Observatory.

STELLAR SPECTRA ON A LARGE SCALE.



Lick Observatory.

1. "FLASH" SPECTRUM OF THE SUN'S EDGE TAKEN AT A TOTAL ECLIPSE.



Mount Wilson Observatory.

2. SPECTRA OF TWO STARS OF GREATLY DIFFERENT LUMINOSITY.

The principal lines which vary with luminosity are indicated by arrows.

THE ATMOSPHERES OF THE PLANETS[1]

By Henry Norris Russell

Research Professor of Astronomy, Princeton University

Two ways are open to the retiring president of this association when he makes what small return he can for the honor of his election. By a sound and time-honored custom, it is his duty and privilege to speak of some topic, within his own technical field, but of general interest. He may therefore either report on his own researches—if he is fortunate enough to have recent or unpublished results good enough to measure up to the standard of a presidential address—or he may survey some section of his part of the field of science in which important gains have lately been made, though his own contribution to this advance may be small. Only the latter course is open to the present speaker, and so, this evening, we may devote a little time to the atmospheres of the planets.

As soon as telescopes became good enough to give a tolerable view of details on the planets, evidence began to accumulate that some of them, at least, possessed atmospheres. Doubtless the first to be noticed were the changes in the markings on Jupiter, which differ radically from one year to the next, and often appear suddenly and last but a few weeks, though thousands of miles in diameter. Only clouds forming and dissolving in a Jovian atmosphere can account for such rapid and capricious changes.

Evidence for an atmosphere on Mars is afforded by the polar caps. The steady shrinkage of these during the summer, accompanied by the growth of the opposite cap during the long, cold polar night, is explicable only by the melting or evaporation of deposits of some snowlike substance, which is carried as invisible vapor to the opposite pole, and there deposited. A permanent, noncondensible atmosphere is required for the transport of this vapor.

Venus, when she is considerably nearer to the earth than to the sun, shows a crescent phase, like that of the moon, and for the same reason. As she comes more nearly into line between us and

[1] Address of the retiring president of the American Association for the Advancement of Science, Pittsburgh, Dec. 31, 1934. Reprinted by permission, with some additions, from Science, vol. 81, no. 2088, Jan. 4, 1935.

the sun, her crescent narrows, and the horns begin to project beyond their normal position, so that she has been seen as three quarters of a circle, and even as a thin bright ring, with a dark interior. This remarkable phenomenon can be seen only when Venus is within about a degree of the sun, and no chance to observe it again will occur till near the end of the present century; but it has been recorded in the past by several competent observers. Such an extension of the horns—and, above all, the ring-phase—can be explained only as effects of twilight, the illuminated atmosphere of the planet being visible across the narrow dark strip of its surface on the side farther from the sun.

For the three brightest planets, then, the presence of an atmosphere is proved by observation, in three quite different, but equally conclusive ways, all of which were well known to astronomers before the end of the eighteenth century.

Later observations have added evidence of the same type—a few white spots on Saturn, appearing at irregular intervals of some decades, which change shape, shift, and disappear as clouds would do—occasional though fugitive clouds, and a measurable effect of twilight, upon Mars; and elusive markings on Venus, which can be photographed only with ultraviolet light, and change greatly between one evening's observations and the next. The extent of atmosphere can also be roughly estimated from the results of direct telescopic observation. The surface details of Jupiter (and of Saturn when any appear) may be seen, and photographed, close up to the limb, despite the very oblique angle of view. It is therefore evident that there can be no such extensive gaseous mantle as veils the earth. At least, there is none above the visible cloud surfaces of these great planets—how much there may be below is another matter. The rarefied layer which exists, however, suffices to cut down the apparent brightness of the edge of the planets' disks. The effect of contrast against a dark sky conceals this in an ordinary telescopic view; but the first look at one of these planets in strong twilight shows that it is actually of surprising magnitude.

There is more "limb-light" on Mars, and there may be more atmosphere above the visible surface—the real surface, this time; but an atmosphere as thick as the earth's, even if free from clouds or haze, would produce a much greater effect.

For Venus the layer which produces the elongation of the crescent is remarkably thin, rising only about 4,000 feet above the visible surface. But this represents only the part of her atmosphere which is hazy enough to be seen through the glare of our own sky close to the sun. The top of the atmosphere must be much higher; and the bottom, if the visible surface is composed of clouds, much lower, so that its whole amount may be great.

The celestial body which we can observe in far the greatest detail tells quite another story. The moon, viewed telescopically, shows no more atmosphere—whether in the artist's or the physicist's sense—than a bare plaster cast illuminated by a powerful searchlight. Far more delicate tests are possible here than in other instances, and neither refraction nor twilight is present to the minutest degree. Our satellite is naked rock in vacuo. Mercury, too, shows little evidence of atmosphere, though Antoniadi reports occasional obscuration of dark markings, which he attributes to dust-haze.

The existence of atmospheres on the majority of the planets, though not on all, is thus established by direct telescopic observation. To determine their composition we must, as usual, have recourse to the spectroscope; but we meet with two difficulties.

In the first place, many possible atmospheric constituents show no selective absorption whatever in the region accessible to our study. Hydrogen, nitrogen, helium, neon, and argon belong in this group, and are hopelessly beyond the reach of our investigation. Secondly, the other gases of the earth's atmosphere absorb too much for our advantage. The worst by far is ozone. Though present in but small amounts, and mainly in the higher layers, it cuts off the whole spectrum short of 2900 angstroms, and deprives us of any hope of studying the most interesting parts of all celestial spectra.

Were we working in the infrared, water vapor would be almost as troublesome. There are long stretches of the solar spectrum, within the range of present-day plates, in which we can find out little or nothing about the sun's own spectrum. The great wide lines of the water-vapor bands, often overlapping, hide almost everything else. The band near 11500 A is quite hopeless; that at 18000 would be worse, if our photographs got so far; one near 9600 is still very bad; while in those near 8200 and 7200 the solar lines can be picked out, with care, among their stronger telluric neighbors.

Oxygen reveals itself by a strong band, with very regularly spaced lines, at $\lambda 7594$ (Fraunhofer's A), the weaker B band near 6867, and the much fainter α band at 6277. The terrestrial origin of all these lines is conclusively settled by two tests: first, their changes with the altitude of the sun (varying the air-path) and, for the water-vapor lines, with weather conditions; second, the absence of the Doppler shift, due to the sun's rotation, when light from the east and west limbs is compared. The absence of even faint components of solar origin is explained by the high temperature, which dissociates such molecules completely.

The intensities of these bands are in inverse order of the abundance of the molecules which produce them—an apparent anomaly, explained by the circumstances of their origin. The ozone band is part of the main system of the O_3 molecule, and, like all such bands,

is very intensely absorbed, a layer of the gas, at its worst, being as opaque as one of metal of equal mass per square centimeter. For water vapor the main absorption bands lie far in the infrared, and are very strong—those with which we are now concerned involve high harmonics of the fundamental vibrations. The coefficient of absorption, and the intensity of the bands, diminishes rapidly with increasing order of the harmonics and diminishing wave length.

The oxygen bands are produced by a "forbidden" transition within the molecule, for which the probability of absorption is exceedingly small. This is why the whole mass of oxygen above our heads (equivalent to a layer 2 kilometers thick at standard temperature and pressure) produces absorption lines no stronger than the sodium vapor in a Bunsen flame an inch thick, which contains but a minute percentage of the vapor of the metal. The principal bands of oxygen, in the ultraviolet beyond $\lambda1800$, are so strong that light of shorter wave length cannot be observed at all in air. The experimenter must put his whole spectroscope in a gastight case, and pump it out to an almost perfect vacuum.

In the visible spectrum, the portions cut out by oxygen or water vapor are very small in extent; but they come exactly in the wrong place—in other words, they hide, line for line, absorption by these same gases which might be produced in the atmosphere of a planet.

If the planet's atmosphere was decidedly richer in either constituent than the earth's, we might detect the fact, for the lines in the planet's spectrum would be stronger than in that of the moon. Comparisons of this sort, however, must be made with great precautions. The moon and planet must be at the same altitude when the observations are made (to get equal air-paths). It is not safe, either, to observe the planet early in the evening and wait till the moon rises to the same height, for a change in temperature may have caused the precipitation of water out of the air, though the oxygen, of course, remains the same. With sufficient patience, a time may be found when planet and moon can be seen together, at equal altitudes, and observed almost simultaneously, with the same instrument.

Early observations of this sort were supposed to show the presence of oxygen and water vapor on Venus and Mars; but the careful and accurate work of Campbell, in 1894, led him to the conclusion that there was no perceptible difference in the strength of the bands in the two cases, and hence that the amounts of these important substances, above the visible surfaces of either planet, did not exceed one-fourth of those above an equal area of the Earth's.

A more delicate and very ingenious test was invented, independently, by two distinguished American observers, Lowell and Campbell. When Mars (or Venus) is approaching us, or receding, most rapidly, the lines in its spectrum are displaced by the Doppler shift,

while lines produced in the Earth's atmosphere are of course unaffected. Were this shift great enough the planetary and telluric lines would appear double, and the former, even though faint, could readily be detected. The greatest available shift is not enough to resolve the lines completely; but measures of the blended lines suffice to show whether any important planetary contribution is present. A still more delicate test is afforded by microphotometer measures of the contours of the lines, which would reveal even a slight asymmetry. These observations are very exacting, requiring high dispersion and a great deal of light, so that the best evidence is that from the great coudé spectrograph of the 100-inch telescope at Mount Wilson. St. John and Nicholson found, in 1922, that there was no perceptible trace of planetary lines in Venus, and Adams and Dunham, in 1934, have come to the same conclusion in the case of Mars. An amount of oxygen, on either planet, equal to a thousandth part of that above an equal area on earth, could certainly have been detected. For water vapor, the tests have so far been less delicate, and are not fully decisive—though the quantity present on either planet must be small. More delicate tests, with stronger lines, may soon be made on new red-sensitive plates.

There can be no reasonable doubt, on quite different evidence, that some small amount of water vapor is actually present in Mars' atmosphere. Radiometric observations of the planet's heat show definitely that the surface rises to temperatures above 0° Centigrade at noon every day in the Martian tropics, and at the pole at midsummer, though falling far below freezing at night. The polar caps must therefore really be composed of snow, and evaporate into water vapor, even if the pressure is so low that the ice turns directly into vapor without melting. The only plausible alternative suggestion—carbon dioxide—would volatilize at much lower temperatures than the actual polar caps do. But, judging from the amount of solar heat available to evaporate them, the polar caps must be very thin, probably only a few inches thick. The vapor resulting from the gradual sublimation would never attain any considerable density, and might easily fail of detection by the tests which have so far been practicable.

No such independent evidence is available for Venus, but Adams and Dunham, in 1932, discovered, in the infrared region of her spectrum, three beautifully defined bands with heads at λ7820, λ7883, and λ8689, and evidently of atmospheric origin. They had not then been observed elsewhere; but an immediate suggestion regarding their origin was obtained from the theory of band-spectra—by that time well developed. The spacing of the individual lines in a band arises from the rotation of the molecule and depends upon its moment of inertia. For the new planetary band, it showed that the otherwise

unknown molecule involved must have a moment of inertia of 70.5×10^{-40} c. g. s. units. This agreed almost exactly with that of the molecule of carbon dioxide—already known from laboratory observations in the infrared. All doubt regarding this identification was removed when Dunham, passing light through 40 meters of CO_2 at a pressure of 10 atmospheres, found that the strongest of the bands found in Venus was faintly absorbed. Recently Adel and Slipher, using a path of 45 meters through gas at 47 atmospheres' pressure, have found the bands considerably weaker than they appear in the planet. They conclude that the amount of carbon dioxide above the visible surface of Venus is at least 2 mile-atmospheres—that is equivalent to a layer 2 miles thick at standard atmospheric pressure and temperature. The whole amount above the planet's solid crust may be much greater. For comparison it may be noted that the whole atmosphere of the earth amounts to 5 mile-atmospheres, and the oxygen in it to one and a quarter.

These bands do not show in the solar spectrum, even when the sun is setting. But there is very little CO_2 in the earth's atmosphere, and the whole amount in the path, even at sunset, amounts to only 30 feet under standard conditions.

The weak absorption in these bands, like that in the visible bands of water vapor, arises because they involve high harmonics of the fundamental vibration-frequencies—in this case the fifth.

So far we have had to do with bands of familiar and readily identified molecules; but the major planets have been much more puzzling.

Jupiter shows a conspicuous band in the orange, which was discovered visually by Huggins in the earliest days of spectroscopy, and fainter ones in the green. These appear more strongly in Saturn, but only in the spectrum of the ball of the planet, and not at all in that of the ring—which might be anticipated, since the ring consists of a multitude of tiny isolated satellites, and should be quite devoid of atmosphere. Uranus, though its light is faint, shows the same bands, much more strongly, and many others in addition. One of these, which closely coincides with the F line of hydrogen (λ 4861) led Huggins to conclude that the planet's atmosphere was rich in hydrogen.

This interpretation, though quite permissible at the time, was erroneous, for the line is absorbed only by dissociated atoms of hydrogen, which will not be present except at very high temperatures.

The bands cut out so much of the red and orange light that the whole disk of Uranus appears decidedly green—an unusual color, noticed from the time of the planet's discovery.

In Neptune's spectrum, the bands are of enormous strength, cutting out the red almost entirely and making the planet look still

greener. They are hard to observe visually in so faint an object, and the full realization of their intensity came only with the admirable photograph of V. M. Slipher, in 1907. In later years, and with modern plates, Slipher has extended his observations far into the red, finding bands of ever-increasing strength—up to λ 10000 for Jupiter, where there is light enough to follow the spectrum farthest.

For more than 60 years after their first discovery, and 25 after Slipher's spectrograms, these bands presented one of the principal unsolved puzzles of spectroscopy—for no one had duplicated them in the laboratory. To be sure, one group, near λ 7200, agrees fairly well with a band of water vapor—but the still stronger water-bands deeper in the red are absent, so that this must be a chance coincidence.

When the radiometric measures of Coblentz and Lampland, and of Nicholson and Pettit, showed that the temperature of the visible surfaces of Jupiter and Saturn must be well below —100° Centigrade—while Uranus and Neptune are doubtless colder—the range of possibilities was very much narrowed. But it was not until 1932 that a young and brilliant German physicist, Rupert Wildt, realized the solution of the problem.

Other gases, like water vapor and carbon dioxide, have strong fundamental absorptions in the infrared, and fainter harmonics in the more accessible part of the spectrum, which demand a long absorbing path in the laboratory to bring them out. Utilizing observations of this sort, Wildt showed that certain bands in the spectrum of Jupiter near λ 6470 and λ 7920 agreed with those of ammonia, and others, at λ 6190, λ 7260, and λ 8860, with bands of methane. The original comparison was not quite conclusive, for with the moderate dispersion then employed the planetary bands had not been adequately resolved into their component lines. This was soon accomplished by Dunham, who found so complete a coincidence of the accurately measured individual lines that both identifications were put beyond all question. For ammonia more than 60 lines were found to agree, and for methane 18 lines in part of one band. Some expected band lines were naturally blended with solar lines, but not one of importance failed to appear.

From these comparisons Dunham estimates that the quantity of ammonia gas above the visible surface of Jupiter is equivalent to a layer 10 meters thick under standard conditions. In Saturn it is less.

The climax of the tale came this year, when Adel and Slipher announced that practically all the bands had been identified, and were due to methane. The 45-meter path and the 40-atmosphere pressure got enough of the gas into the way of the light to produce bands intermediate in intensity between those in Jupiter and in Saturn.

At this high pressure the lines flowed together, and produced diffuse bands; but the agreement of these with the planetary bands was so complete as to be decisive.

A further, and wholly conclusive, test could be added. The fundamental frequencies of vibration of the methane molecule were already known, from observations in the infrared. For the higher harmonics of these vibrations the frequencies are not exact multiples of the lowest, but nevertheless bear a simple numerical relation to them (as is well known in the case of other gases). Applying this test, the strongest bands (including Huggins' band in the orange, and the one coincident with the blue hydrogen line) were found to be harmonics, from the third to the eighth, of one of the fundamental frequencies, while another slower vibration was represented by all its harmonics from the eighth to the sixteenth. The remaining bands were accounted for by combinations of these harmonics with other known frequencies, all of types consistent with the well-established rules which govern band spectra. Forty-one bands in all have been identified. Many of these appear only in Uranus and Neptune, and have not yet been produced in the laboratory, but the harmonic relations just mentioned make their identification certain. The higher gaseous hydrocarbons, ethane, ethylene, and acetylene, all have bands in places clear of disturbance by the methane; and all were looked for in vain. All the planetary bands of any importance are accounted for by methane alone—it is a clean sweep.

From the published data, it appears that the amount of methane above the visible surface of Jupiter is of the order of one mile-atmosphere. There must be much more on Uranus, and especially on Neptune—25-mile atmospheres, according to Slipher and Adel.

There is still plenty of work to do upon these bands, but mainly for the theoretical investigator. Adel calculates that the band at λ 5430, when fully resolved, should consist of 18 different overlapping systems of many lines each. Fortunately, the astrophysicist need not wait to draw his conclusions till this has been completely analyzed.

The results of observation can be summarized in a sentence. Large planets have atmospheres containing hydrogen compounds; middle-sized planets, atmospheres containing oxygen compounds; and small planets no atmospheres at all. The reason, in the last case, was found by Johnstone Stoney, in 1897. It is simply that small bodies have not sufficient gravitative power to keep their atmospheres from diffusing away into the vacuum of interplanetary space. At the surface of any planet, there is a certain velocity of escape, depending only on its mass and radius. A body projected from its surface, in whatever direction, with this or any higher velocity, will fly off in a parabolic or hyperbolic orbit and never return—unless, indeed,

it meets with some obstacle or resistance on its outward way. For the moon this velocity is 2.4 kilometers per second; for the earth, 11.2; for Jupiter, 60.

Now the molecules of any gas are continually flying about in all directions, with average speeds which depend upon their weights. At 0° Centigrade the average speed for a hydrogen molecule is 1.84 km/sec.; for oxygen, 0.46; for carbon dioxide, 0.39. If an atmosphere of hydrogen could be put upon the moon, every molecule that was moving but a little faster than the average would fly off at once into space, unless it was thrown back by collision with another, and the atmosphere would diffuse away in a very short time. With an escape velocity three times the average speed, enough fast-moving molecules would get away to reduce the atmosphere to half its original amount in a few weeks (according to Jeans). The rate of loss falls off very rapidly beyond this, so that, with an average velocity one fifth that of escape, the atmosphere would remain for hundreds of millions of years.

The moon's surface reaches a temperature exceeding 100° C. during every rotation, and it follows that neither air nor water vapor could permanently remain above its surface. If at any time in its past history, it has been really hot, like molten lava, it could have retained no trace of atmosphere. For Mercury, the escape velocity is half as great again as for the moon; but the planet, being so near the sun, is much hotter, and it can hold only the heaviest gases. Mars, with an escape velocity of 5 km/sec., could not hold hydrogen but should retain water vapor—as it appears to have done—and all heavier gases. Venus and the earth, at their present temperatures, should retain even hydrogen, and the major planets would do so even if incandescent.

This reasoning explains the cases of Mercury and the moon, and leads to the important conclusion that all smaller bodies, such as the asteroids and satellites, must be wholly devoid of atmosphere—except perhaps bodies like Neptune's satellite, which is relatively massive, and must be very cold. We cannot be sure about Pluto, for we know neither its size nor its mass; but it is probable that, at most, it may have a thin atmosphere, like Mars.

The same principle was invoked, shortly after its discovery, to explain the great difference in mean density between the major and the terrestrial planets. The moon, Mercury, Mars, Venus, and the earth all have densities between 3.3 and 5.5 times that of water. The rest are almost certainly what we know the earth to be, spheroids of rock, with cores of metallic iron of varying sizes. For the major planets, the densities range from 1.6 for Neptune to 0.7 for Saturn. Moulton suggested, about 1900, that they contained great quantities

of light substances, which the smaller terrestrial planets had not been able to keep from diffusing away into space. This has been fully confirmed by later studies.

From the ellipticity of a planet and the changes in its satellites' orbits caused by the attraction of its equatorial bulge, information may be obtained regarding the degree to which the density increases toward its center. Applying this to Jupiter and Saturn, Jeffreys concludes that they contain cores of rock and metal, like the inner planets, surrounded by vast shells of ice—frozen oceans thousands of miles deep—and above this, again, atmospheres of great extent. Throughout most of the atmospheres, the pressure must be so great that the gas is reduced to a density as great as it would have if liquefied, or even solidified, by cooling. Indeed, Wildt believes that the enormous pressure would actually solidify even the "permanent" gases.

Now this outer layer is of low density—less than 0.78 for Jupiter and 0.41 for Saturn—according to Wildt's calculations. This excludes all but a few possible constituents. Frozen oxygen has a density of 1.45, nitrogen 1.02, ammonia 0.82. Only hydrocarbons (methane 0.42, ethane 0.55), helium (0.19), and hydrogen (0.08) come within the limits even for Jupiter. We can therefore conclude, from considerations of density alone, that the outer parts of Jupiter probably, and of Saturn certainly, contain great quantities of free hydrogen or helium. Uranus and Neptune are similar to Jupiter.

It is generally believed that the planets have been produced, in some way or other, from matter ejected or removed from the sun. No really satisfactory theory of the process of formation has yet been devised; but no other hypothesis has yet done better, and the isolation of the sun and planets in space makes a common origin highly probable.

Now we know the composition of the sun—at least of its outer layers—much better than we do that of the planets. Quantitative spectroscopic analysis, though still beset with difficulties, has advanced far enough to show that most of the sun's outer layers is composed of hydrogen; next come helium, oxygen, and carbon, followed by nitrogen, then silicon and the metals. A mass of matter removed from the sun and allowed to cool without serious loss would therefore closely resemble the major planets. If small enough to lose all its atmosphere, it would be like the moon or the asteroids—though there are difficulties in seeing how such small masses could have escaped diffusing away altogether before the more refractory constituents solidified.

The history of a body of intermediate mass is more interesting. Hydrogen and helium would be lost while it was still very hot. So

would most of the other light gases such as neon and nitrogen (which at the temperature even of the sun's surface is dissociated into atoms). Free oxygen, too, would escape, but a good deal might be retained in combination with silicon and the metals. As the gaseous mass cooled, by expansion and radiation, drops of molten metal and lava would form within it, as Jeffreys suggests, and fall toward the center, building up a molten core. After the first turbulence was over, there would remain a molten planet surrounded by an atmosphere containing heavy inert gases, such as argon, perhaps some carbon dioxide, and as much of the nitrogen and neon as had failed to escape. Menzel and I, a few years ago, noticed that neon, while apparently fully as abundant in the stars and nebulae as argon, is but $\frac{1}{500}$ as abundant in the earth's atmosphere; while nitrogen, which is cosmically an abundant element, showing strong spectral lines, forms but a very small portion of the earth's mass. It appears, therefore, that a mass of the earth's magnitude must have lost almost, though not quite, the whole of its primitive atmosphere.

Still following Jeffreys, it appears that, as the molten earth cooled, the 2,000-mile deep sea of lava solidified first at the bottom (where the melting point was greatly raised by pressure) and so gradually to the surface. During this process great quantities of gases, mainly water vapor, must have been evolved from the solidifying magma, and escaped to the surface, forming a new atmosphere which now would not escape, since the surface was cooler. With solidification would come rapid superficial cooling, and an ocean would bathe the rocky crust, leaving an atmosphere of moderate extent. Carbon dioxide—evolved from the magma, and perhaps partly primitive—would be a major constituent, along with nitrogen, argon, neon, and other minor left-overs. The presence of free oxygen seems very unlikely, for practically all volcanic rocks and gases are unsaturated with respect to this element—the former containing much ferrous iron and the latter being often actually combustible when they meet the air.

The present rich supply of oxygen appears to be a byproduct of terrestial life. (This suggestion is more than a century old.) The earth, indeed, may be regarded as an intensively vegetated planet, from whose atmosphere the greedy plants extract the remaining residue of carbon dioxide so rapidly that if it were not returned to the air by combustion, respiration, and decay, the whole supply would be exhausted in a decade or so. Oxygen removed from the atmosphere by these processes is speedily returned by plants; but there is another process of slow depletion which is irreversible. During rock-weathering, about half the ferrous iron of the rocks is oxidized to the ferric state. Goldschmidt (from whose admirable

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geochemical papers the present discussion is borrowed) concludes that the amount of "fossil" oxygen thus buried in the sedimentary rocks is at least as great as that now present in the atmosphere and may be twice as great. An amount of carbonaceous or other organically reduced material equivalent to both the free and the fossil oxygen must also be in the sediments—which is not unreasonable. Given time enough, this inexorable process of rock-decay might exhaust the remaining oxygen of our atmosphere and put an end to all that breathes. But this danger is indefinitely remote—a billion years away anyhow, since life has lasted that long and only half the oxygen has been used up; and probably much longer, for volcanic gases are still carrying "juvenile" carbon dioxide into the air that has never been there before.

It is of no small interest, however, to look at Mars and see there what looks very like the end of this process. The reddish color of the planet—unique among the heavenly bodies—is just what might be expected, and indeed is almost inevitable in a surface stained with ferric compounds. (The unoxidized rocks of the moon are gray or, at most, brownish.) Wildt suggests that, in the thin atmosphere of Mars, the ozonized layer produced by the action of ultraviolet light at the top of the atmosphere should be near the surface—not high up, as it is here—and that oxidation processes at the planet's surface might thus be accelerated.

It would be premature, however, to conclude that Mars must be a lifeless planet. The depletion of oxygen would be very slow, and plant life would probably adjust itself, as it has done on the earth in response to far more rapid climatic changes. Whether animal life, if ever present, could have survived is speculation. A race of no more intelligence and engineering skill than our own could presumably meet the situation and survive in diminished numbers breathing electrolytic oxygen, provided that it paid any attention to changes so slow as to be imperceptible in a thousand generations.

While Mars resembles the final stage of our suggested process, Venus seems to be at the beginning, and much like what a lifeless earth would be. We do not know how life began here, but conditions may well have been much less favorable on Venus. Wildt concludes that the powerful "blanketing" effect of the atmospheric CO_2, combined with the stronger solar radiation, may raise the temperature at the planet's actual surface to 100° C. or higher, in which case the failure of life to develop is not surprising. The real puzzle is the apparent absence of water on Venus' surface. She is almost a twin of the earth in size, mass, density, and so on, and one might have expected an ocean of comparable volume. Wildt suggests that all

the water has gone into hydrated minerals; but how this could happen, unless there was much less there originally than on earth is hard to understand.

For the major planets we have to consider the course of events in a cooling mass containing an excess of the lighter elements and especially of hydrogen. The condensation of the refractory constituents should take place much as for a smaller body. The principal constituents of the rocks, however—potassium, sodium, magnesium, aluminium, calcium, and silicon—are not reduced from their oxides by hydrogen, and would form rocks not unlike those of the earth. But at high temperatures the oxides of iron are reduced by hydrogen. My colleague, Prof. H. S. Taylor, to whom I am greatly indebted for counsel on these problems of physical chemistry, remarks that the drops of molten lava falling through a hydrogen atmosphere reproduce pretty closely the conditions of a blast furnace. We may conclude then that most of the iron would go into the core and less into the rocky shell.

After the shell solidifies, the remainder of the mass will remain fluid over a wide range of temperature. Its principal elementary constituents will be hydrogen, helium, oxygen, carbon, and nitrogen, with smaller quantities of the other inert gases, sulphur and the halogens.

The principal reactions which occur in such a gaseous medium at different temperatures and pressures have been carefully studied, for, in addition to their theoretical interest, they are of great practical importance in chemical industry.

When oxygen, carbon, and hydrogen are considered the main reaction is

$$CO_2 + 4H_2 \leftrightarrows CH_4 + 2H_2O$$

The formation of methane is accompanied by diminution of volume; hence it will be favored by high pressure. High temperature works the other way; from the free-energy data it appears that, at 1,000° C. and atmospheric pressure, the equilibrium inclines to the side of carbon dioxide, even in the presence of a large excess of hydrogen. Below 300° C. practically all the carbon should go into methane; at about 600° the amounts of the two gases should be comparable.

With hydrogen and higher hydrocarbons the tendency of the reaction is always toward methane at low temperatures. With saturated hydrocarbons, this involves no change of volume and should not be affected by pressure. Formation of methane from unsaturated hydrocarbons should be favored by high pressure. The exclusive presence of methane in the planets' atmospheres might thus have been predicted.

The formation of ammonia from its elements, in accordance with the equation

$$N_2+3H_2 \leftrightarrows 2NH_3$$

liberates less energy. With excess of hydrogen, and at atmospheric pressure, the amounts of nitrogen and ammonia should be equal between 200° and 300° C.; ammonia should predominate at lower temperatures and at higher pressures.

The oxides of nitrogen are endothermic and so would tend to dissociate, rather than to form.

We may now form a definite picture of the successive reactions which will occur in the atmosphere of a cooling major planet. At temperatures of about 1,000° the predominant hydrogen will be mixed with steam, free nitrogen, and carbon dioxide; the carbon monoxide which occurs in stellar atmospheres having long ago been completely oxidized. With falling temperature the carbon dioxide will be converted into methane before the water reaches its critical temperature and begins to condense. After most of it has been precipitated, the nitrogen will go over into ammonia. These reactions, however, will run their course at these relatively low temperatures only with appropriate activation. For the formation of methane an excellent catalyst is available in the partially reduced oxides of iron which should be present on the rocky surface exposed to hot hydrogen. These would be equally good for the ammonia, but they may be at the bottom of the sea by the time the proper temperature is reached. An adequate activation, however, would be furnished by electrical discharges, and if terrestrial thunderstorms are any guide, these should be abundant so long as vapors arising from the hot ocean are being condensed. When the temperature has fallen to that which the earth at present enjoys, there will be an extensive atmosphere of hydrogen, mixed with the simple hydrides—methane, ammonia, and water vapor—along with any inert gases which may all along have been present, but with little or no free nitrogen or carbon dioxide. Below this will be an ocean, perhaps very deep, strongly alkaline with ammonia, and incidentally containing in solution any compounds of sulphur and the halogens which may originally have been present. The conditions in such an alkaline ocean—its action on the rocky bed, the compounds which it will hold in solution, and the deposits which it may form—would be of great interest, but are outside our present scope.

With further cooling the water will freeze, but at a temperature below 0° C. depending on the percentage of ammonia. With one part of the latter to two of water the freezing point would drop to −100° C., but it is doubtful if there is enough ammonia for this. The major planets—even Jupiter—are still colder, and the water

must be thoroughly frozen out of their atmospheres, leaving only ammonia and methane. The ammonia, indeed, must be at the point of precipitation. Dunham has obtained in this way a minimum temperature for Jupiter's visible surface. The 10 meters of ammonia above the surface, under the planet's surface gravity, should exert a pressure of 1.5 mm (on the familiar laboratory scale). The vapor tension of the solid (below the triple point) has this value at −107° C. At a lower temperature the observed quantity of ammonia could not exist in the atmosphere—it would partially condense itself by its own weight.

If the atmosphere consists mainly of hydrogen, this limit may be lower, for the mean molecular weight is diminished, and the partial pressure of the ammonia in the same proportion. With a large excess of hydrogen the pressure may be reduced to one-sixth of the previous value and the limiting temperature to −120° C.

The direct radiometric observations of Jupiter indicate a temperature of about −135°; but this determination is complicated by large and rather uncertain corrections for the absorption of infrared radiation in the atmospheres of the earth and the planet, so that the agreement is about as good as could be expected. It is, therefore, very probable that the clouds which form Jupiter's surface are composed of minute crystals of frozen ammonia. A perfectly absorbing and radiating planet, at Jupiter's distance and heated exclusively by the sun, would have a mean temperature of −151° C. The excess in the actual temperature may be attributed partly to the fact that we observe the sunlit (and warmer) side; partly to the "greenhouse" effect of the atmosphere, which lets in the short-wave radiation from the sun much more easily than it lets the long waves emitted from the planet's surface out again; and partly, perhaps, to some residual internal heat in the planet. The existence of the latter is made probable by the rapid changes in the cloud forms, which often suggest the ascent of new material from below. The variety of colors upon the surface, which range from clear white through pinks and browns almost to black, remains unexplained.

On Saturn, where the ammonia bands are fainter than on Jupiter and the surface gravity less than half as great, the limiting temperature may be 10° or 15° lower. The radiometric observations indicate about the same difference.

Uranus and Neptune, being farther from the sun, should be still colder. The ammonia should be frozen out of their atmospheres, leaving them clear to a greater depth, which may explain the extraordinary strength of the methane bands in their spectra. The methane itself must be nearly ready to condense on Neptune, despite its very low boiling point. Assuming, roughly, that Neptune has

six mile-atmospheres of methane above its surface, the pressure, due to this alone, would be about 500 mm and the limiting temperature −165° C. A large excess of hydrogen might reduce this to −183°. Solar radiation alone would maintain a mean temperature near −220°. Whether the difference arises from the powerful "green-house" effect of the methane itself, or from internal heat, cannot yet be determined. It may be, however, that if the methane could once be frozen out of Neptune's atmosphere, the surface temperature would fall so much that it would stay frozen and leave the planet with an atmosphere which, apart from the inevitable Rayleigh scattering, exerted no influence upon visible light.

The problem of planetary atmospheres, so perplexing a few years ago, is now far advanced toward its solution. Toward its interpretation many of the sciences have contributed—astronomy, physics, chemistry, geology, biology, and technology. No one of them alone could have resolved the difficulties. It may, therefore, be appropriate that the attention of so general a scientific gathering may have been invited for a while to it, for it truly illustrates the old motto, "In union there is strength."

THE SURFACE FEATURES OF THE MOON[1]

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[With 4 plates]

The moon needs no introduction. It has been known to all of us from early childhood when we first tried to reach out and touch it and later learned to decipher both the man and the lady in the moon. In spite of this general interest and friendly feeling toward the moon, the president of the Carnegie Institution of Washington realized several years ago that its presence in the night sky is resented by the modern astronomer, especially the astrophysicist. Its light interferes with the photography and analysis of far-distant, faint celestial objects, such as stars, clusters, and nebulae—incandescent masses of enormous size, radiating huge amounts of energy into space and of special significance because they yield information on the extent of the universe and on the behavior and structure of matter under conditions of temperature and pressure not attainable in the laboratory. These remote, active heavenly bodies appeal to the imagination and offer problems of the most fascinating kind for solution. The astrophysicist is occupied with receiving and interpreting their messages. He learns little in this field from the moon. To him it is a lifeless, inert mass, shining only by reflected sunlight and held by gravitation in its orbit about the earth. From an astronomical viewpoint, the moon is an insignificant object only 2,160 miles in diameter; the sun is nearly a million (864,000) miles in diameter. To us the moon appears large because it is distant only 30 earth's diameters, or 240,000 miles. Viewed through a large telescope it appears to be only 200 or 300 miles away and details 500 feet apart can be distinguished under conditions of good seeing.

To the layman, not versed in astrophysics, the moon is the most conspicuous object in the night sky and the rival of all heavenly objects, even including the sun itself. It has played a significant

[1] This article presents the progress made by the committee on study of the surface features of the moon of the Carnegie Institution of Washington, of which the author is chairman. Reprinted by permission from The Scientific Monthly, vol. 40, pp. 101–115, February 1935.

part in many phases of human activity. To it we owe the first subdivision of the year into months and weeks, even though in our present calendar the lunar cycle is disregarded. The words moon and month are derived from the same Sanskrit root, mâs, meaning to measure. To our primitive ancestors the moon was an object of worship; they observed and tried to explain its changes in aspect and in position among the stars from day to day. Together with the sun it is responsible for the tides, so important to navigation. Its light illuminates the sky at night during a part of each month and its moonbeams are said to be an important factor in certain human decisions. To the formulation of the law of gravitation and to the development of dynamical astronomy it contributed much, but to modern astrophysics it has added little and it cannot compete with other heavenly bodies as an object of study. The astronomer of today does not appreciate the moon as did Milton when he wrote in Paradise Lost:

> * * * The moon
> Rising in clouded majesty, at length
> Apparent queen, unveiled her peerless light
> And over the dark her silver mantle threw.

In 1609 Galileo first observed through his telescope the surface features of the moon, its craters, mountains, and great plains or seas, as he called them. Realizing that the moon is a companion of the earth and, as he thought, a world not unlike our own, he was impressed by the features which he saw, and sought to interpret them in terms of terrestrial features. To him and to his contemporaries his telescope seemed to disclose a new world. Following his lead, astronomers undertook serious study of the moon's surface. During the next 3 centuries a vast amount of observational data on lunar surface features was accumulated and many lunar maps were published. As a result, the geography or rather selenography of the moon is well known; no part of the moon's surface visible to us has been left unexplored. Furthermore, selenologists have sought to explain the mode of formation of the different features on the moon's surface and have suggested all manner of hypotheses to account for them. In spite of all this labor we do not yet know definitely the exact nature of the lunar surface materials, nor how any single lunar feature was formed. No critical study and classification of lunar surface features have been made and no lunar maps free from the personal factor have been prepared.

COOPERATIVE APPROACH

At the time the committee on study of the surface features of the moon was appointed, Dr. John C. Merriam felt that attack by a cooperative Carnegie Institution group might be fruitful of

results, especially if the experience from several branches of science could be brought to bear upon it. Accordingly, he chose for membership on the committee four astrophysicists, one mathematical physicist, one geophysicist, and two geologists.[2] The committee was given no specific instruction other than that implied in its title; it was afforded opportunity to contribute toward the solution of a most attractive problem, in part astrophysical, in part geological.

This policy of assigning to an interdepartmental committee a problem of large scope is in keeping with the general policy of the Carnegie Institution of supporting organized efforts in fields of science too large for one man to encompass. In the early days of science it was possible for one person to master all existing knowledge in his own field; advances were then made chiefly through the efforts of individual scientists working alone. These men laid the foundations on which modern science is being built. Each department of the Carnegie Institution is essentially a group of cooperating scientists, each member carrying on research activities of his own, but also doing his share of cooperative work. This group method of facing each problem from all standpoints and determining the best means for solving it is followed not only within each group, but also between the several groups within the institution and between the institution and outside agencies. The dividends accruing from cooperative work of this kind, in terms of scientific results obtained for a given sum of money, are unusually large, chiefly because of facilities and the background of experience within the several groups. Were it not for this factor, the special interdepartmental and other cooperative activities would be less successful. On the other hand, the drawback to committee work of this nature is that no member can devote much time to it; results are, therefore, gathered slowly and the effort is spread over many years.

PRELIMINARY SURVEY

As a preliminary to experimental work on the problems presented by study of the surface features of the moon the committee undertook to survey the field and to analyze the present status of the problem. It sought to visualize the conditions existing at the moon's surface. The observer cannot journey to the moon and gather samples, make maps, and plot the field relations on the spot. In geological field work geologists have become accustomed to judge of the relative effectiveness of different terrestrial agencies and are inclined to interpret what they see in terms of terrestrial factors or processes

[2] Members of the committee are: W. S. Adams, F. G. Pease, and E. Pettit, of Mount Wilson Observatory; A. L. Day and F. E. Wright (chairman), of the Geophysical Laboratory; and research associates, H. N. Russell, of Princeton University, J. P. Buwalda and P. Epstein, of the California Institute of Technology.

with which they have had experience. Moreover, the geologist sees what he has been trained to see and overlooks much that he would otherwise see had he the necessary background of experience. In study of the surface features of the moon he is confronted with conditions with which he has had no contact. Lunar surface features have been sculptured by catastrophic agents of different kinds and not by the action of running water, or by erosion and deposition in the usual sense, or by ordinary wind action, or by weathering. Gravity is only one-sixth of that on the earth; a mass of rock weighing a ton on the earth would weigh only 333 pounds on the moon. At the moon's surface there is no water, no ice; no protective blanket of atmosphere to soften the impact of the sun's rays and to prevent the escape of heat radiated from the moon's surface. The temperature ranges are extreme. At midday on the moon, with the sun directly overhead, the surface temperature is approximately 120° C. (250° F.) or above that of boiling water; at midnight it falls to below −100° C. (−150° F.). In spite of this extreme range in surface temperatures it is probable that a few feet below the lunar surface the inflow of sun's radiation maintains a temperature not far from freezing, or 0° C.

It is not an easy task for the geologist to adjust his mental attitude to such extreme conditions. He has become accustomed, on viewing a given terrestrial surface feature, to inquire (*a*) of what kinds of rocks or materials does it consist; (*b*) what geological agents, operating on the original rock mass, have given the surface feature its present shape? He has learned to recognize the imprint or earmark of each kind of geological agent and seeks in a given case to ascertain what combination of geological agents or processes, acting one after the other or together, have produced the surface feature under study. By this method he is able to read and to interpret geological history as it is written in the rocks and on their surface. In his study of the surface features of the moon he is confronted with physiographic forms which, in part, are quite unlike anything he has seen on the earth; also, he misses the familiar effects of erosion. To him the surface of the moon presents a weird picture. He realizes that before he can begin to make progress on lunar physiographic problems, he must first ascertain the nature of the materials which he sees exposed on the moon; then determine how those materials behave under the known lunar surface conditions. In other words, he must acquire a good working knowledge of the petrology of the lunar surface materials. In addition, he needs a good lunar map, preferably a topographic map, by use of which he can obtain an idea of the spatial relations of the different features. This is asking a good deal and the task might seem hopeless were it not for the

fact that messengers are continually reaching us from the moon in the form of reflected sun's rays; they will teach us much if we can decipher and interpret their messages correctly.

THE MOON'S SURFACE

The general features of the moon's surface are shown in plates 2 to 4. The dark smooth areas of plates 2 and 4 are called seas or maria; the lighter areas bordering the maria are the mountains; the features of circular outline are called craters because of their resemblance to terrestrial craters. The craters dominate many parts of the moon's surface and are remarkable for their range in size and for their frequency. Of small craters there are literally thousands spread over the surface of the moon. The larger craters greatly exceed in dimensions terrestrial craters. Many of the craters, located in the maria, have smooth floors, level with the ground of the surrounding country; other craters are much deeper and less smooth; in many of these craters there is a central hill or series of peaks which rise from the crater floor; on several of these peaks there is perched, in turn, a small crater (pl. 3). The area covered by a mare is greater than that of any one of the great plains regions of the earth. Mare Imbrium, which occupies the central portion of plate 2, is 800 miles across. The maria are relatively late formations and spread, as floods over preexisting craters and other features, submerging them either completely or nearly so.

One of the most impressive craters on the moon is Copernicus (pl. 3); it is 56 miles across and 13,500 feet deep, about as deep as Mount Blanc is high, and with central hills rising 2,400 feet above its floor. The simplest method for measuring the elevation of a lunar feature above the adjacent country is to ascertain the length of its shadow when it is near the terminator or the limit of illumination across the moon's disk. We know at any given time and for any point on the moon's surface the angle which the sun's rays make with the vertical to the moon's surface at that point, so that it is a simple task to compute from the given angle and the length of the shadow the height of the feature casting the shadow. Another method is based on the shift in longitude relations between adjacent features of different elevations with changes in libration. Still another method is the stereoscopic method, which also is based on phenomena due to libration. The terraced inner walls of Copernicus are conspicuous; also the rays or streaks which emanate from it and extend for great distances across Mare Imbrium. The most pronounced rays, however, radiate from Tycho (pl. 4); this crater is 54 miles across and 17,000 feet deep; a central hill rises 5,200 feet from its floor. It is located in a part of the moon which is dominated by craters large and small and of different ages. The more

recent craters are more sharply outlined and are lighter in color, as a general rule. Not far above Tycho in plate 4 is located Clavius, a magnificent crater 142 miles in diameter, 17,000 feet deep, and containing smaller craters, one of which is larger than any terrestrial crater. In this figure also a fault scarp is shown in the mare below Tycho which is called the " Straight Wall "; it is 70 miles long with a downthrow of nearly 1,000 feet on the east.

Study of the mountainous areas in the photographs and on other parts of the moon shows that they are unlike terrestrial mountains and are for the geologist and the astronomer exceedingly difficult to interpret. The heights of the mountains reach 25,000 feet in isolated cases; the deepest crater has a depth of 24,000 feet. The lunar mountains are extremely rough and would be difficult to traverse, even if there were water and air present to support life. This is not the place to discuss the many hypotheses which have been suggested to account for the mode of formation of the different types of lunar surface features. Suffice it to state that no single hypothesis has been adequately proved so that it can be accepted without reservations. Each hypothesis contains certain elements of truth. With reference to the volcanic theory of the origin of the craters, the observed intimate relationship between lunar crustal structure and the occurrence of craters indicates that some of the craters, at least, are due to volcanic action. On the other hand, the translational energy of a meteor impinging unimpeded on the moon with a velocity of 20 to 40 kilometers a second and penetrating into the surface for some distance is able not only to produce the crater form, but also, on transformation of the residual kinetic energy into heat, to melt and even to volatilize the country rock and thus set up actions which in their effects would closely resemble volcanic phenomena. In this connection the low lunar gravity is an important factor.

From a geological standpoint the absence of water and air on the moon together with its low gravity are factors favorable to the development and maintenance of extremes in surface forms. One of the results of low gravity and the lack of air resistance is the greatly increased length, twenty-five to fifty fold, of trajectories of materials thrown out of lunar craters as compared with the trajectories of materials ejected at the same initial velocity and angle of elevation on the earth. For a muzzle velocity of 1,600 meters (5,250 feet) per second, equal to that of the Big Bertha gun which the Germans used against Paris during the World War, the terrestrial range for an elevation angle of 50° is 75 miles; on the moon the maximum range for this initial velocity is 2,200 miles, or more than one-quarter of the distance around the moon. The rays from Tycho have been

traced for approximately 1,500 miles; for this distance an initial velocity of 1,480 meters (4,856 feet) per second is required and an elevation angle of 26°. An initial velocity of ejection from terrestrial volcanoes exceeding 2 kilometers a second has been deduced from observations of the volcano Cotopaxi. It is evident, therefore, that the ranges of ejection on the moon can easily have been produced by volcanic explosive forces comparable to those active on the earth. On the moon the materials ejected from a lunar crater are scattered far and wide, whereas on the earth the greater part of the ejected rock fragments and blocks fall near and into the crater orifice. As a result of this dispersion the lunar craters are cleaned out as a rule and are of the nature of deep holes in the ground with the floor of the crater below the level of the surrounding country; the floors of terrestrial craters, on the other hand, are near the top of the crater and high above the level of the adjacent country. This is one of the factors to be taken into account in a study of lunar craters. It is not permissible to conclude that, because the shape of a lunar crater is similar to that of a terrestrial crater the mode of formation of the two was the same.

MAPPING THE MOON

Before the geologist can make satisfactory progress in lunar physiographic studies he must have a topographic map, at least of the central portion, to aid him in visualizing the shapes of the lunar surface features and of their relations one to another. He can then classify the features, and by studying them in detail can acquire a background of experience in lunar geology which is necessary to competent interpretation of the phenomena observed.

Of maps there are two kinds, the plan or base map and the topographic. Thus far, for the moon, only the first kind has been attempted. It represents the moon's globular surface projected on a definite plane and shows the features somewhat as the astronomer sees them through his telescope. These maps have been drawn by astronomers untrained in the principles of map-making, with the result that existing maps are unsatisfactory in several respects; the balance between map scale and amount of detail shown is not realized and some of the maps are not easily legible; several lunar maps have been prepared by men who were good observers, but not good draughtsmen and unable to portray what they saw. In other words, the existing maps suffer from the personal equations of the men who drew them. Comparison of a lunar map made a century ago with one made recently shows marked differences in the representation of certain features; on the basis of such a comparison it has been concluded that changes have taken place here and there

on the moon. But astronomers do not agree as to the validity of any single change, and the bulk of the available evidence goes to show that there has been no appreciable change on the moon's surface within the past century.

It seemed, therefore, to the moon committee that a lunar map should be prepared which is free from the personal equation and not dependent on the skill of the observer to depict correctly what he sees on the surface of the moon. The positions of approximately 4,000 points on the moon's surface have been accurately measured by Saunders, Franz, and others and expressed in terms of selenographic longitude and latitude. With the aid of these data on position it is possible to ascertain the amount and direction of libration in each photograph of the moon. If each photograph could be transformed so that its plane coincides with the plane of mean libration, namely, the plane on which all lunar maps are projected, the transformed photograph would form part of a lunar map and at the same time be free from the personal equation of the one who makes the map. To prepare a photographic map of the moon it is necessary to transform photographs taken with the aid of the 100-inch telescope at Mount Wilson so that the plane of projection is the same for all photographs. A map is a projection on a definite plane; the type of projection and the plane of projection must be quite definite if the map is to be satisfactory. For the transformation of the photographs a special moon house has been built at Mount Wilson. It is a specially insulated structure with double walls, corrugated sheet iron on the outside and paper on the inside with ventilation between the walls so that they quickly respond to temperature changes outside. The floor is covered with a layer of sawdust 6 inches thick to prevent radiation from the ground. As a result, the temperature distribution within the 150-foot building is remarkably uniform and seeing conditions are good so long as the temperature outside is not changing rapidly and there is no appreciable wind.

To transform a given moon photograph taken at the Cassegrain focus of the 100-inch telescope (focal length 135 feet), the moon positive, 15 inches in diameter, is mounted in front of a powerful beam of light reflected by an Army searchlight mirror 3 feet in diameter; the light passes through the positive to a parabolic silvered mirror of 67.5 feet focal length and 135 feet distant and thence back to a carefully turned globe of bronze, 15 inches in diameter and coated with magnesia powder. This coating furnishes a white diffuse reflecting surface. The image of the moon formed on it is in all respects similar to the moon in the relations of the surface features one to the other; in other words, it is a miniature moon which can be photographed from any direction. For this

purpose a second reflecting mirror, also of 67.5 feet focal length, is placed at such a position that it views the moon from the direction of mean libration and casts an image of it on a photographic plate mounted in a compartment beside the illuminated globe. The photographs thus produced are projections on the plane of mean libration; they fulfill the requirements of a map on a given scale. In order to complete the series of maps showing the moon at different phases we still need photographs taken with the 100-inch telescope and its zero corrector lens. During the past 2 years the seeing conditions at Mount Wilson have not been such that we could obtain photographs of the quality desired for this purpose. The series of maps made by this method will be independent of the personal factor and be more valuable a century hence than at present.

PHOTOGRAPH OF MOON ON GLOBE

The projection of the moon positive on the magnesia-coated globe gives a surprisingly beautiful and realistic representation of the moon's surface. The correct and undistorted appearance of the craters and other features near the edge of the moon's disk is of great aid in the visualization of the surface relationships. In order to make this globular representation more accessible, a glass globe coated on the outside with photographic emulsion was substituted for the magnesia-coated bronze globe and the moon negative projected on it, thus producing a moon transparency which is angle true. The globe is frosted on the inside and illuminated by an electric bulb. The coating with photographic emulsion was done, through the courtesy of Dr. C. E. K. Mees, by the Research Laboratory of the Eastman Kodak Co., and represents a new advance in photographic technique. A dozen of these globes have been prepared; they will be useful to the moon committee in its physiographic work later; they may also serve as exhibits of miniature moons showing the moon at different phases.

The committee has also devised a method for making a topographic map of the central part of the moon out to 45° from the center and with contour intervals of 500 feet or 200 meters. For the preparation of this map advantage is taken of the libration of the moon to obtain stereoscopic images from which, in turn, the relative elevations can be ascertained by applying the principle used in areal mapping from airplane photographs; with this difference, however, that in airplane mapping the surface of reference or datum plane is a horizontal plane, whereas on the moon we are interested in the elevations with reference to a mean spherical surface. The apparatus has not yet been built, and we shall not stop to consider details of the method.

SURFACE COMPOSITION

We come now to the problem of ascertaining the nature of the materials exposed at the surface of the moon. Obviously, we are limited, in our approach to the problem, to a determination of the effects which the materials have on sunlight on reflection. One and a quarter seconds after the sun's rays leave the moon they reach the earth. We can study and measure these reflected rays by different methods and compare them with direct rays from the sun. We can also study and measure the changes produced in sun's rays on reflection by terrestrial materials, such as rocks of various kinds and other substances. These changes are not limited to the visible spectrum, but include all the radiation received through the earth's atmosphere from the ultraviolet into the infrared. The effects

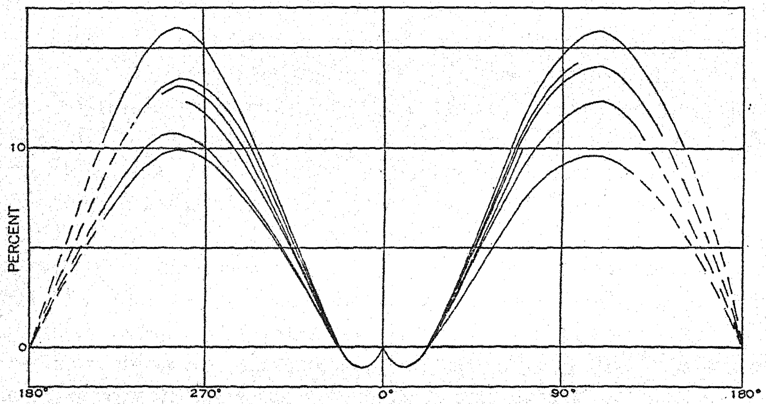


FIGURE 1.—Change in plane polarization of moonlight from maria. The curves show the changes in percentage plane polarization of moonlight from different lunar maria with change in phase angle.

produced are of two kinds: A certain amount of plane polarization is introduced and different parts of the spectrum are reflected to different degrees. Light is considered to be caused by vibrations in a special medium. These vibrations take place, in free space, at right angles to the direction of propagation. If the vibrations are limited to a single plane, containing the direction of propagation and a line perpendicular thereto, the light is said to be plane polarized. White light consists of vibrations of different frequencies; it can be resolved into its component parts or frequencies by the use of a spectroscope or spectrograph. The human eye is sensitive to a small part only of the range of radiation frequencies; this part is called the visible spectrum; those portions which are beyond the power of the eye to sense are called the ultraviolet and the infrared, respectively, when the frequencies are higher or lower than the frequencies in the visible spectrum.

Thus far we have used, and are still using, four different methods for these measurements; a visual method employing a special polarization eyepiece for the measurement of the amount of plane polarization in the rays for different points on the moon's surface and at different phases of the moon; a photoelectric-cell method for the measurement both of the amount of plane polarization and of the relative spectral intensities of the rays; a thermoelement method for the same purpose; and a polarization spectrograph. These methods require special apparatus, devised or adapted to the problem in hand. The moon is an unusually favorable object for the testing of new methods and apparatus suitable for analyzing the characteristics of sunlight reflected by a planet or satellite of the solar system.

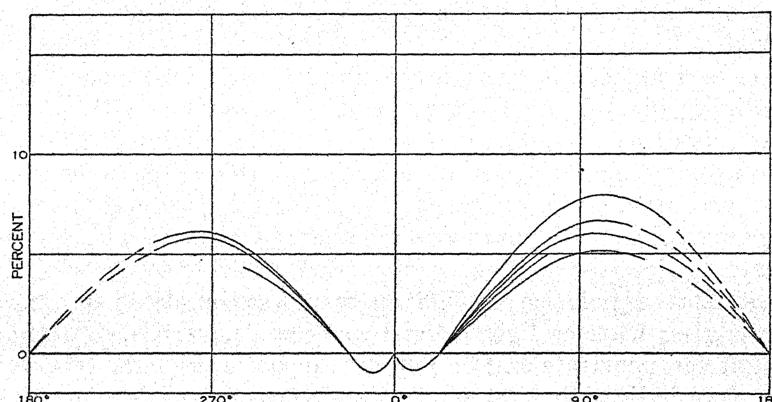


FIGURE 2.—Change in polarization in moonlight from mountains. The curves show the changes in percentage plane polarization of moonlight from different mountainous areas with change in phase angle.

For the visual measurements a special eyepiece enables us to ascertain the percentage plane polarization in a moonbeam accurate to one-fifth of 1 percent. The field of the eyepiece is a divided photometric field in which two factors, equality of illumination and exact alignment of Savart fringes, are the two criteria used in making a measurement; it is the combination of these two factors which renders the method so accurate. With the aid of this eyepiece 24 selected small areas on the moon have been studied and the amounts of plane polarization in the reflected light measured for different phases of the moon. The measurements extended over four lunations, and nearly 10,000 individual readings with the new eyepiece mounted on a 6-inch refracting telescope were made, so that we now know with a fair degree of certainty the amount of plane polarization present in a beam of moonlight from any given area on the moon at any given phase. The general results are shown in figures 1 and 2. On an average the mountains and lighter areas reflect

more light and contain approximately half as much plane polarized light as the light from the maria and other dark areas. The maximum polarization occurs at the lunar phase angles, 100° to 110° and 280° to 290°, and attains the maximum value of 16 percent in the case of 1 or 2 maria. The plane of vibration is commonly normal to the plane of incidence; but near full moon the polarization is negative and the plane of vibration is in the plane of incidence. At phase angles, ±22° to 23°, the polarization is zero for practically all points on the moon's surface. It is also zero for phase angles 0° (full moon) and 180° (new moon). This negative polarization, first discovered by Lyot, attains a value roughly of 1 percent as a rule. It is an abnormal phenomenon and is probably due to diffraction and scattering. It is also observed on terrestrial materials.

Measurements of the percentage amounts of plane polarization in sunlight reflected by terrestrial materials are being made with the new eyepiece; they are not yet complete. When finished, they will enable us to group the materials according to this property and thus to ascertain with a fair degree of probability the nature of the lunar surface materials. We know from measurements made with the less accurate predecessor to this eyepiece that dark, opaque rocks and other substances polarize the light more or less completely at certain phase angles; whereas light-colored rocks and materials, into which the light can penetrate and be reflected, polarize the light relatively little, thus indicating that the lunar surface materials are of the latter type. Additional evidence that the surface materials are of the nature of volcanic ashes and pumice, high in silica, is given by the rate of cooling of the moon's surface during an eclipse. As the earth's shadow passes over the moon its surface temperature drops, in the course of an hour, from +120° C. to below −100° C., according to measurements by Pettit and Nicholson of Mount Wilson Observatory. This signifies, as computations by Dr. Epstein of our committee show, that the lunar surface materials are exceedingly good heat insulators; in other words, they have very small heat capacity, are poor heat conductors and cannot, therefore, be massive materials, like granite or limestone, but rather light substances resembling, in characteristics, pumice and volcanic ashes.

Measurements by the three other methods, photoelectric cell, thermoelement, and the polarization spectrograph, are now in progress. In these three methods the special apparatus is mounted on a 20-inch reflecting telescope and the light from a given small area on the moon is received on the light-sensitive receiver. The photoelectric cell attachment consists of a special large compound Wollaston prism of quartz in a rotatable mount, a vacuum potassium Kunz

photocell of fused quartz, and the special amplifying circuit of DuBridge and Brown adapted and improved by Dr. Stebbins and employing the new electrometer tube D–96475, of the Western Electric Company. A more refined apparatus of this type is employed by Dr. Stebbins in his work with the photoelectric cell on the stars and nebulae. The thermoelement is of the vacuum type, made by Dr. E. Pettit, and is equipped with the rotatable compound Wollaston prism of quartz; like the photocell, it is used together with ray filters to isolate certain parts of the spectrum. The thermoelement is not nearly so sensitive as the photocell, but it extends over the entire spectrum and is useful as a check on the other measurements. The polarization spectrograph is of the ultraviolet type, but also serves throughout the visible spectrum. In the parallel beam between the collimator and the first prism a Wollaston prism of quartz in a sliding mount can be inserted and two spectra obtained, the one with vibrations in the plane of incidence and the second with vibrations normal thereto. Approximately 200 spectrograms of different parts of the moon were taken with this spectrograph during the past summer. The spectrograms yield information both on the percentage polarization for any given wave length and on the relative intensities for different wave lengths. Although not so sensitive as the photoelectric cell, the polarization spectrograph covers a much wider range of wave lengths, through the ultraviolet into the deep red of the visible spectrum.

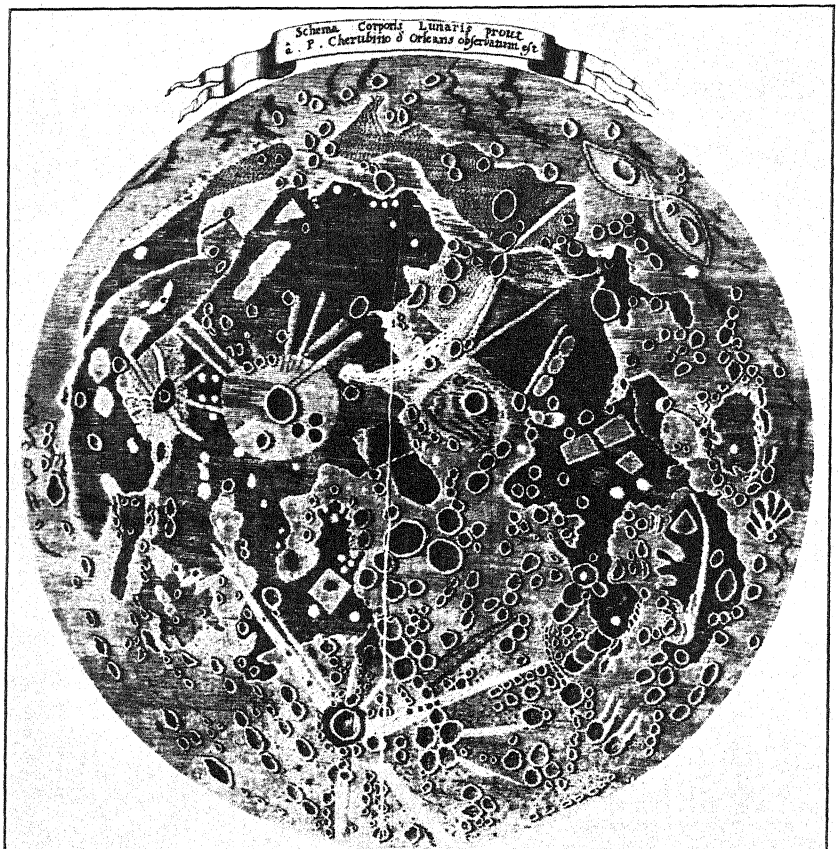
PROGRAM FOR FURTHER WORK

We plan to complete these measurements within the next 2 or 3 years; also to measure the changes in polarization of total moonlight with change in phase and for different parts of the spectrum; also the change in total intensity of moonlight with change in phase; also to obtain additional photographs of satisfactory quality to enable us to proceed with the preparation of the photographic lunar map. We are working along quite definite lines with apparatus and methods developed in detail. We shall gather data of measurement which should enable us to ascertain with fair certainty what the lunar surface materials are and how they are disposed over the surface of the moon insofar as it is visible to us. With that information available, together with a good lunar map and a knowledge of the conditions existing at the surface of the moon, we shall be in a position to attack the problem of the physiography and mode of formation of the lunar surface features.

The questions arise: Why should a problem of this sort be solved? Why should a scientist give his time and energy to their solution? These are proper questions and they should be faced. The scientific

spirit of the investigator impels him to search after the truth and to do so by experiment and measurement. His interest is objective and is centered chiefly in the overcoming of difficulties incident to the pioneer work of advancing knowledge. For the most part he is the expert workman, operating through his fingers, using tools of his own design and adding his bit to the fund of knowledge. In the case of a problem like that of the moon, he does not inquire too closely into the immediate usefulness of the results obtained; his first desire and task is to devise methods and apparatus adequate for the attack. The routine measurements needed to obtain the results are a necessary step toward the solution. That these methods and devices will have application to other problems of similar nature is to him a satisfaction; but the real incentive is the game of overcoming the difficulties inherent in the problem.

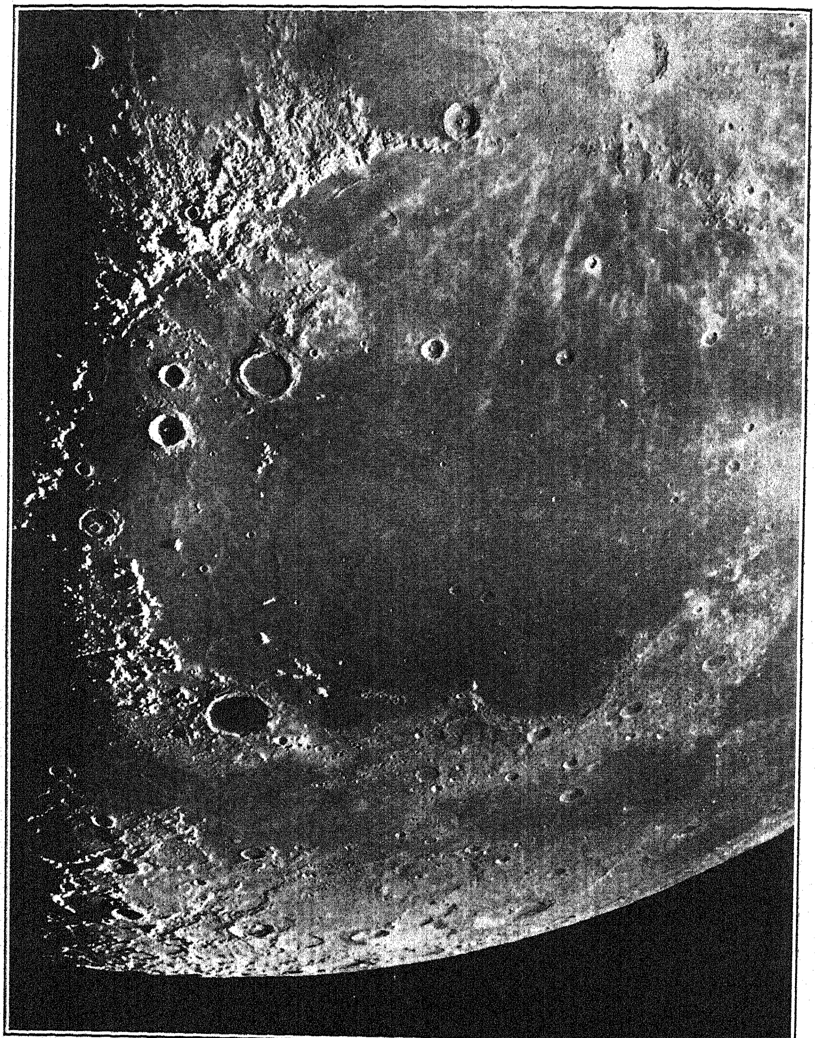
Experience has shown that scientific research work does yield returns, even when the research problem is in the field of astronomy. The several fields of science are so intimately related that advance in the one field commonly means advance in another. The practical applications of the results of science and of its method of approach have meant much to us in a physical and materialistic sense; but equally important is the training in attitude of mind toward nature, its constancy and reliability. We research workers fail in our task if we do not pass on some of the inspiration we derive from close contact with nature, its forces, and factors which are quite beyond our comprehension. We glimpse these elements from afar and realize with humility how limited is our understanding of even simple things. But we do sense a goal which, if it were more generally realized, would add stability and proper placing of emphasis on the things that count and tend to bring us into accord with the principles of life which endure and have stood the test of time and human experience.



Dr. J. C. Hostetter.

EARLY SKETCH MAP OF THE MOON.

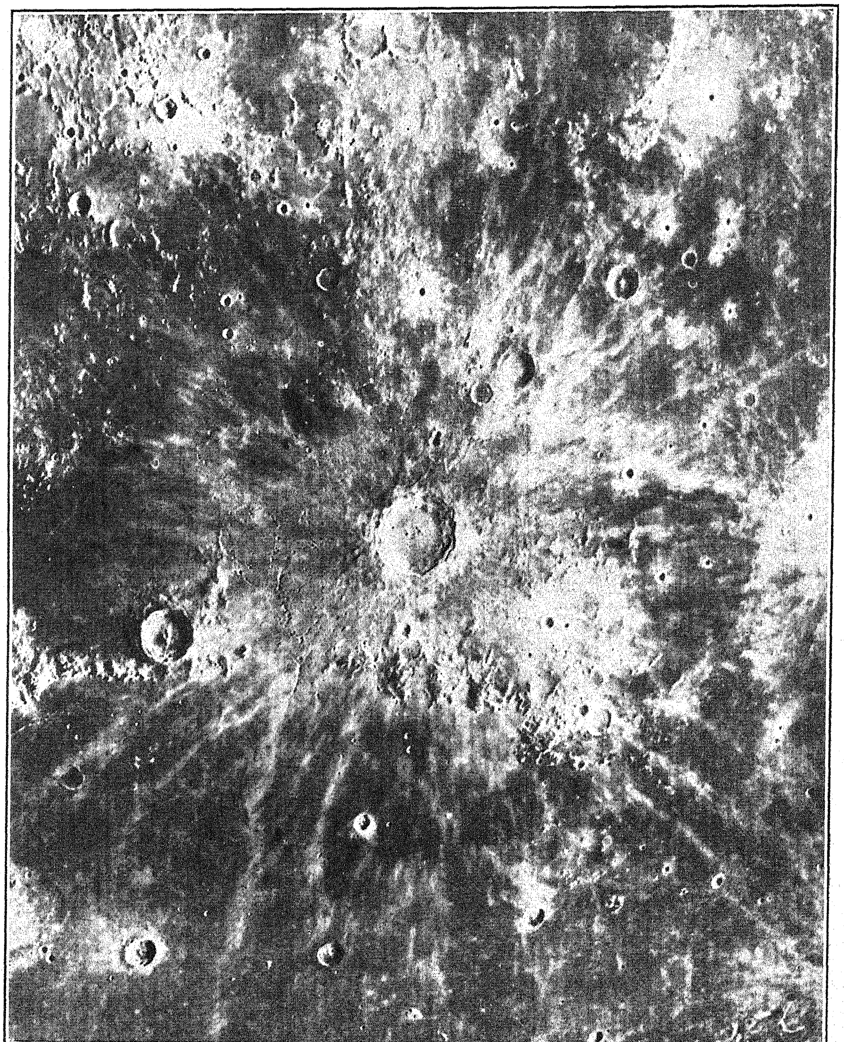
Prepared by P. Cherubino d'Orleans. Published in the book "Oculus Artificialis Teledioptricus sive Telescopium", by J. Zahn, Norimbergae, 1702.



F. G. Pease, Mount Wilson Observatory, Sept. 15, 1919.

NORTHEAST PORTION OF MOON'S SURFACE.

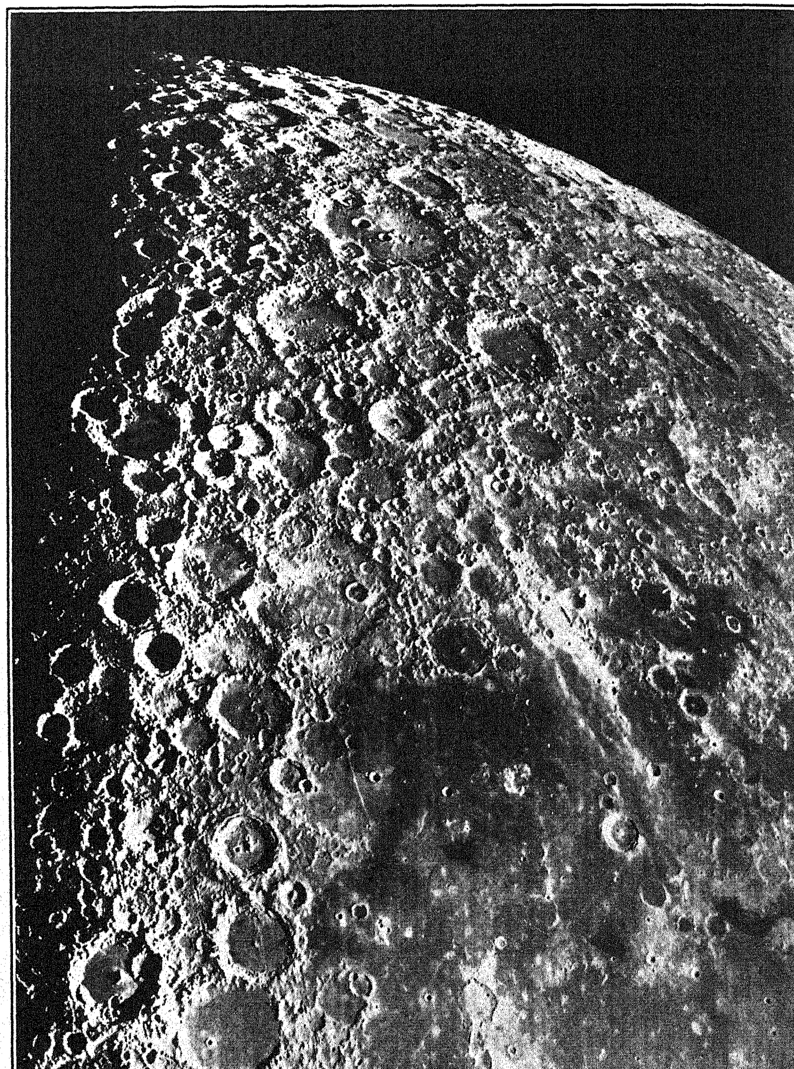
Mare Imbrium occupies the central part of this view. It is 800 miles across and is bordered by high mountains of strange aspect. Observe the diversity in sizes and characteristics of the circular features or craters.



F. G. Pease, Mount Wilson Observatory, Sept. 15, 1919.

EAST CENTRAL PORTION OF MOON'S SURFACE.

Copernicus is a magnificent crater 56 miles across and dominates this "metropolitan" area of the moon. Observe the streaks of light materials which radiate from Copernicus.



F. G. Pease, Mount Wilson Observatory, Sept. 15, 1919.

SOUTHEAST SECTION OF MOON'S SURFACE.

The large sharply defined crater near the center of the view is Tycho. It is 17,000 feet deep and 54 mil across; from it white streaks radiate for long distances. Clavius, a still larger crater, 142 miles i diameter and located above Tycho, is one of the most interesting features on the moon.

THE UPPER ATMOSPHERE[1]

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Recent progress in the investigation of the upper regions of the earth's atmosphere has been mainly along two different lines. The first is connected with what may be called the meteorological state of the atmosphere, namely, its temperature, density, etc., while the second has to do with its electrical characteristics. Many balloons carrying meteorological instruments have been sent up, but the great majority of these have failed to reach a height of 25 kilometers. In a few cases where specially large balloons were used a height of 30 kilometers has been reached and a balloon sent up in Russia has recently been reported to have reached 40 kilometers. In order to obtain information about the atmosphere at still greater heights it is necessary to employ indirect methods of exploring the atmosphere. Fortunately, several such indirect methods are available and it is our present purpose to describe them and the results that have been obtained from them.

Meteorological conditions below 20 kilometers.—From the large number of sounding balloons which have been sent up in many countries carrying recording instruments the general meteorological conditions of the air up to 20 kilometers are now fairly well known. In the lower part of the atmosphere the temperature falls with increasing height at a rate of about 6° C. for every kilometer rise. The exact rate at which the temperature falls differs from day to day and may be different at one height from that at another height. The fall of temperature with height does not, however, continue indefinitely, but at some fairly well-defined height it stops and the temperature from this point upward is found to change but little as the balloon ascends to its greatest height. The height where the temperature ceases to fall—known as the Tropopause—is usually between 8 and 14 kilometers in Europe.

The results from recording balloons thus show that the atmosphere is divided into two parts by its thermal structure; the lower

[1] Reprinted by permission from Science Progress, vol. 30, no. 117, July 1935.

part, in which the temperature falls with increasing height, is known as the troposphere and the upper part as the stratosphere. The conditions in these two regions do not remain constant from place to place nor from day to day. Over the Equator the lower air is naturally warmer than that over the polar regions, but over the Equator the troposphere extends to an average height of some 17 to 18 kilometers. As the temperature is falling at a rate of some 6° C. for every kilometer throughout all this height, it is very low by the time the stratosphere is reached, being about 80° C. below zero. In polar regions the stratosphere comes relatively low down and begins at a height of 6 to 8 kilometers, with the result that though the temperature of the air at ground level is very low there is no great difference between the air at the surface and that in the stratosphere, and the latter has a temperature of about 40° C. below zero. The temperature of the stratosphere over the polar regions is thus much warmer than that over the Equator, and as there is little change of temperature with height in the stratosphere we find the rather surprising result that at a height of 16 to 20 kilometers the air over the polar regions is much warmer than that at the same height over the Equator. Indeed, the coldest air in the atmosphere is probably that at a height of 18 kilometers over the Equator.

The conditions of the air in both the troposphere and stratosphere also vary from day to day, and these variations are closely associated with the meteorological situation. When a well-defined depression has just passed across the country, it will be found that the troposphere is colder than usual, that the stratosphere is abnormally low and that its temperature is above the average. On the other hand, when a well-marked anticyclone covers the country the troposphere will be warm, the stratosphere cold, and the tropopause high. It will be seen that these changes are similar to the changes with latitude, so that the conditions in middle latitudes in the rear of a depression are similar to those in polar regions and the conditions in an anticyclone are similar to those in equatorial regions.

Meteorology of the upper atmosphere.—What has been described above has now been known for several years, but until recently little was known about the conditions above 20 kilometers, and it was usually supposed that the temperature would remain roughly constant up to very great heights. This view was questioned when the results of observations of meteors passing through the upper atmosphere were used to give a rough idea of the temperature at these heights. Contrary to expectation, it appeared that the temperature rose again above the stratosphere and became as warm or warmer than the air at ground level. These results were, how-

ever, very rough, chiefly because it was not possible to get accurate measurements of the brightness and speed of the meteors.

The idea that the air at a height of some 50 kilometers might be warm was found to fit in with the observations of sound heard at a great distance from its source, and such observations have now been used to give us a much better knowledge of the temperatures at heights of between 40 and 70 kilometers above the surface. When a large explosion occurs, the sound is heard for many miles around, but not to such great distances as might be expected. That the sound is not heard farther away is largely due to the fact that sound travels faster in warm air than in cold air. Since in the lower atmosphere, the temperature falls with increasing height, sound travels faster through surface air than through the air a little higher up. Thus the sound waves near the surface run ahead of those above, with the result that the sound ray is bent upward, away from the ground.

The bending of sound waves upward is well seen in the fact that sounds in a valley are often heard much more clearly on the hills on either side than at places the same distance away in the bottom of the valley. Now, in the case of very large explosions it is frequently found that while the sound cannot be heard for more than 20 or 30 miles round the explosion, it is heard again at places very much farther away, perhaps a hundred miles from the explosion, and often heard quite loudly. Such cases as the firing of salvos by the fleet often show this phenomenon, and in a recent case when the fleet was off Portland Bill the firing was heard as far away as Surrey and Oxfordshire but not at many intervening places.

The sound waves which are heard at these great distances are found to have taken some 2 minutes longer over their journey than they should have done had they traveled direct through the lower atmosphere. From this and the fact that they are not heard at intermediate distances, it seems clear that the sound has traveled up into the upper atmosphere and then been deflected back to the ground. This curious behavior had been known for a long time and several explanations had been suggested to account for the fact that the sound is deflected back to earth by the upper air. One suggestion was that the upper air was largely composed of hydrogen, and since it is known that sound travels faster in hydrogen than in oxygen and nitrogen, this would account for the downward bending of the sound rays. None of these explanations, however, carried conviction until Dr. Whipple pointed out that if the temperature rose again at very great heights, as was suggested from the meteor results, then the sound rays would be bent down on entering this upper warmer region in just the same way as they are bent upward by the fall of temperature in the air near the ground.

This last explanation seems quite satisfactory and its importance is that it gives a method of measuring the temperature of the air at the great heights reached by the sound waves. By using special microphones instead of the ear it is possible to detect the waves from the firing of one big gun at a distance of a hundred miles or more. It is easy to measure the total time taken by the sound to travel along its path to the upper atmosphere and back, and further, by a suitable arrangement of three microphones at the receiving station, it is possible to measure the angle at which the downcoming sound ray strikes the earth's surface. Given such observations, it is not

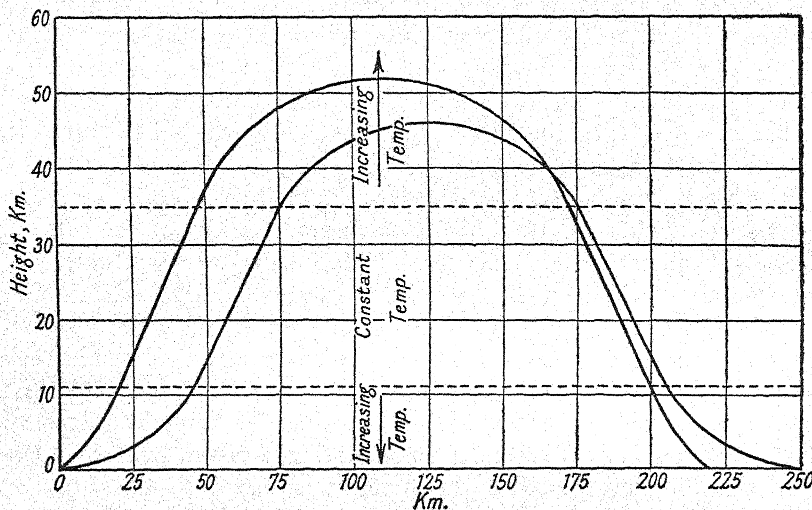

FIGURE 1.—The passage of sound waves to great distances. (After Whipple.) The diagram represents a vertical section of the atmosphere and shows two paths by which sound waves may travel to great distances via the upper atmosphere. The source of the sound is at the bottom left-hand corner. The sound waves are bent upward in the lowest region and downward in the upper region owing to the opposite temperature gradients in these regions. In the middle region of constant temperature the sound travels straight.

difficult to calculate most of the details about the path traveled by the sound, such as the maximum height above the ground and the speed of sound at that height. Then, since the speed depends on the temperature of the air, it is possible to estimate the temperature of the atmosphere at these great heights.

Not infrequently two or more sets of downcoming waves are recorded at a great distance which all come from one single explosion, the waves being separated from each other by several seconds and the angle at which they strike the earth being different in each case. In such cases it is clear that the waves have traveled through the upper atmosphere by different paths, reaching different maximum heights before finally converging on to the recording microphones.

Such a complication instead of obscuring the results only gives increased information, since each set of waves can be treated separately and the temperature can be found for the different heights to which they have penetrated. Thus we get not only the temperature at one height but that at two or more heights and so the rate of rise of temperature with height. This rise of temperature is found to begin at a height of about 35 kilometers and is at a rate of about 6° C. per kilometer of height and is therefore roughly the same as the rate of decrease of temperature with height in the troposphere. It is not yet certain how far this increase of temperature with height continues, but it appears that the temperature has risen to about 100° C.—the boiling point of water—at a height of 60 to 70 kilometers and that it is still higher above.

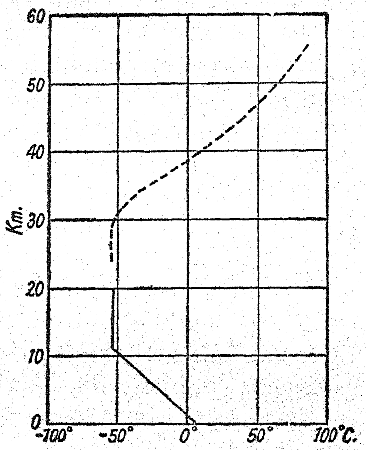

FIGURE 2.—Probable distribution of temperature with height over England. The continuous line from the ground level to 20 km shows the average temperature as obtained from balloon ascents. The dotted line indicates the probable temperature as obtained from sound waves.

Up to the present time most of the observations of the upper-air temperatures by means of sound waves have been made in Europe, but it seems now to be established that the upper warm region extends over the Equator at much the same height as in Europe, while it has been found in polar regions also. When it is possible to accumulate more observations it will be interesting to determine the diurnal and annual variation of temperature at these great heights, as well as to see if there are day to day changes in temperature associated with weather conditions similar to those found at lower levels. Unfortunately, the cost of special explosions is high and most of the observations made in this country have utilized the sound from big guns which were fired for other purposes. It is a curious circumstance, probably due to wind at great heights, that the sound is hardly ever heard to the west of the source in winter nor to the east of it in summer.

Cause of the warmth at great heights.—The temperature of the air in the troposphere, where there is constant mixing of the air between various levels, is governed largely by the supply of heat constantly received by contact with the warm ground. In the stratosphere, and above, the conditions are different and there is little or no mixing with the air below. Here the temperature depends on the absorption and emission of radiation. Radiation from the sun—largely in the form of visible light—passes inward through

the atmosphere and an equal amount of energy passes outward from the earth in the form of dark heat radiation. Only certain gases in the atmosphere take part in this absorption and emission of radiation; nitrogen, for example, is nearly transparent to all the types of radiation passing through the atmosphere, but oxygen, ozone, and water vapor strongly absorb and radiate certain particular types, being transparent to others. Thus oxygen strongly absorbs the radiation of the very shortest wave lengths received from the sun, namely the extreme ultraviolet radiation. Ozone strongly absorbs radiation of rather longer wave lengths though still in the invisible ultraviolet region of the spectrum, and also absorbs a little in the yellow-green, and again a little in the long-wave infrared region. Oxygen and ozone together absorb about 6 percent of the total energy of the sun coming to the earth, and since the absorption is very strong this energy is absorbed by the air at a very great height in the atmosphere. Water vapor is nearly transparent to all the visible and ultraviolet radiation received from the sun, but strongly absorbs most of the long-wave infrared radiation emitted by the earth.

The radiation from all bodies at temperatures below red heat takes the form chiefly of infrared radiation. Oxygen and ozone can emit little radiation of this kind, so that the loss of heat by emission of radiation is chiefly due to the water vapor present. If only water vapor were present, it would absorb little energy from the sunlight but would absorb the infrared radiation emitted by the earth and would bring the air to a temperature of about 50° C. below zero, at which temperature it would be absorbing and emitting equal amounts of radiation so that its temperature would remain constant. It is this process which chiefly governs the temperature of the stratosphere, as oxygen and ozone do not play any appreciable part here, because all the solar radiation which they could have absorbed has already been absorbed much higher in the atmosphere.

Passing now to the extreme upper limits of the atmosphere we come to the region where oxygen and ozone absorb the 6 percent of the sunlight mentioned before. This amount of energy is very large and at these heights there is not much water vapor, so that the atmosphere cannot easily lose heat by radiation. The result naturally is that the temperature of the air rises very much until the small amount of water vapor present is able to emit as much energy as is absorbed. Thus it will be seen that the actual temperature at any level depends on the amount and character of the radiation absorbed and radiated away and therefore on the relative amounts of water vapor and oxygen and ozone which are present.

If we knew the amount of oxygen, ozone, and water vapor present at every height in the atmosphere it would be possible to calculate

the temperature at all levels. The vertical distribution of oxygen can be assumed without any great error, and the distribution of the ozone has been measured, but we are still without reliable knowledge of the amount of water vapor at heights above 20 kilometers. Assuming various distributions of these gases Dr. Gowan has calcu-

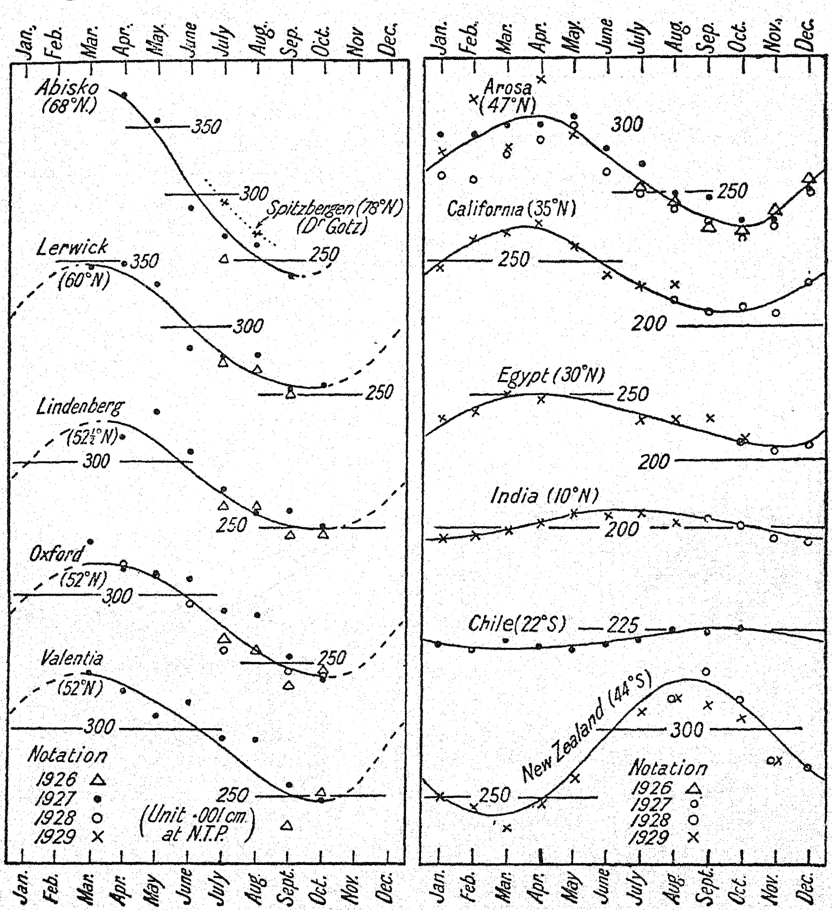

FIGURE 3.—Annual variation of ozone. The curves show the smooth annual variations in the total ozone content of the atmosphere over different parts of the world. The points represent the mean monthly observed values. Note that the amount of ozone is large in spring and small in autumn in both hemispheres. [Figures 3, 4, 5, and 6 are reproduced from the Proceedings of the Royal Society by permission of the Council.]

lated what would be the temperature of the air at great heights. His results show that there should be a marked rise of temperature of the air in the region about 40 kilometers, agreeing reasonably well with the actual temperatures found from sound-wave observations.

The ozone in the atmosphere.—Both oxygen and ozone are responsible for causing the air to be warm at great heights, but the

effect of oxygen is greatest in the upper parts of the warm region, while the effect of the ozone is greatest in the lower parts of that region. A point of great interest is that while the amount of oxygen is constant, the amount of ozone varies greatly. Further, these variations in the amount of ozone are found to be closely associated with the weather conditions as seen on the weather maps for

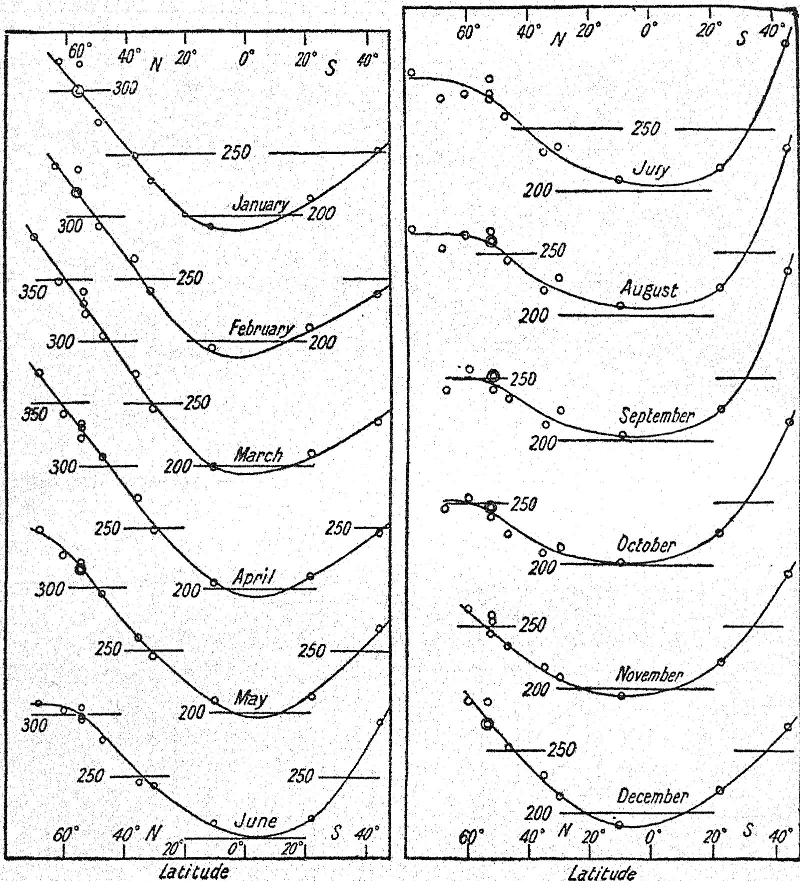

FIGURE 4.—Variation of ozone with latitude. The curves depend on the same observations as were used for figure 3, but now arranged to show the variation of the ozone content with latitude. Note the rapid increase toward polar regions in spring.

ground level. The total amount of ozone in the atmosphere is very small, but since it absorbs the ultraviolet part of sunlight very strongly, its effects are of great importance. How very small the amount of ozone is may be seen in the following way: If all the air in the atmosphere were formed into a layer of uniform density, equal to that of surface air, there would be a layer 8 kilometers deep.

If all the oxygen were separated from the other gases and formed into a similar layer by itself, it would make a layer about 1,700 meters deep. If the same were done for the ozone in the atmosphere, we should find a layer only about 3 millimeters deep on the average. In other words the ratio of ozone to oxygen is as 3 millimeters to 1,700 meters. This small amount of ozone is not distributed uniformly through the atmosphere but is chiefly found at great heights. There is a little present in the surface air and the proportion of ozone to the other gases increases with height until the maximum proportion is found at a height of about 35 kilometers.

Besides varying with the weather conditions, the amount of ozone in the atmosphere has a well-marked seasonal variation and also varies from one part of the earth to another in a regular manner according to the latitude. Both these effects are shown in figures 3 and 4, from which it will be seen that the amount of ozone is generally large in the spring and small in the autumn. This annual variation increases from almost nothing near the Equator to a large range in high altitudes. Moreover, the total amount of ozone is, in general, least at the Equator and greatest in high latitudes.

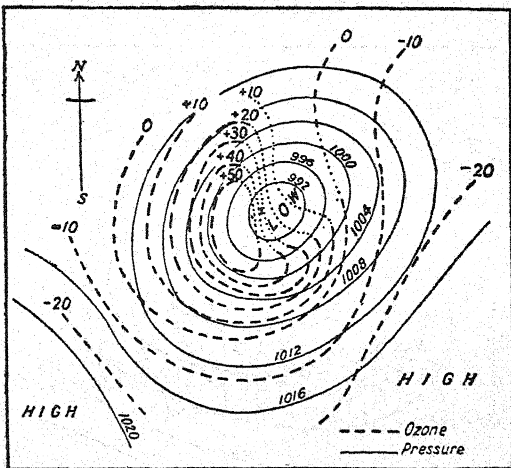

FIGURE 5.—Ozone in cyclonic areas. The continuous lines are drawn to represent a typical cyclonic depression of middle latitudes. The thick broken lines show the distribution of ozone: plus values show that the ozone is above the normal, while minus values show that it is below the normal. *Note the marked concentration of ozone to the west and southwest of the center of the depression.*

It is however, the changes in the ozone content of the atmosphere with weather conditions that is of the greatest interest. Figures 5 and 6 show a typical depression and anticyclone, the thin continuous lines being isobars. The thick broken lines indicate the ozone distribution in these two pressure systems. The figures do not relate to any one particular case, but are the result of measurements on a large number of occasions. Any one particular depression or anticyclone may show minor differences, but the same general features are found in nearly every case.

The amount of ozone in the atmosphere is measured by spectroscopic observations of sunlight, in which the amount of the absorp-

tion of the ultraviolet light by the ozone is determined. To obtain the results used to construct figures 5 and 6 a number of spectrographs were made and distributed over Europe, and spectra were taken of sunlight on every day that the sun was visible. Naturally, on many of the days when, from the meteorological conditions, we should most have liked to have measurements, the sun was completely hidden by clouds and observations were impossible. More recently another instrument has been made by which the amount of ozone can be obtained on almost any day with great ease. Unfortunately these new instruments are expensive and it has not yet been possible to make a number of them and to have measurements made regularly at a number of places in Europe in order to study in detail the connection between the amount of ozone and the weather conditions. Such a study might reveal the real nature of this connection and be of great value in weather forecasting.

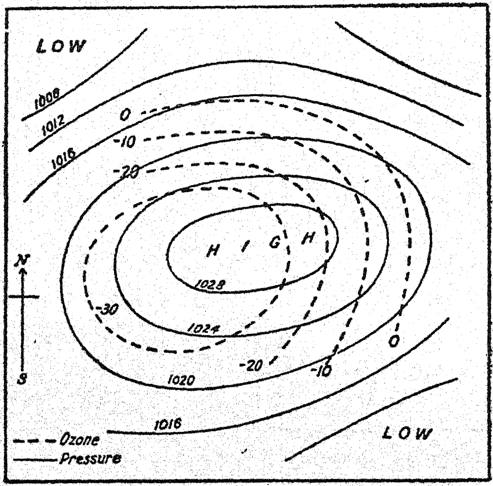

FIGURE 6.—Ozone in anticyclonic areas. The continuous and dotted lines are as for figure 5. Note that the ozone values are low over the whole area.

Already we know that the amount of ozone is very closely associated with many meteorological conditions in the upper air. When the troposphere is warm, the ozone content is usually high and vice versa. It is also closely connected with the pressure of the air at great heights, the amount of ozone being small when the pressure is high. The closest connection yet found is between the amount of ozone and the density of the air at a height of about 18 kilometers, or, what is nearly the same thing, the amount of heat the air has absorbed. The reason for these connections is not known at present, but they may clearly have an important bearing on meteorology when they are thoroughly understood. At present further progress is largely dependent on money with which to make the necessary instruments.

ELECTRICAL CHARACTERISTICS OF THE UPPER ATMOSPHERE

Results from terrestrial magnetism.—The first suggestion that the upper atmosphere was a good conductor of electricity resulted from a study of the magnetic field of the earth. Accurate measurements

of the strength and direction of the magnetic force of the earth show that this force is not constant but varies both in strength and direction. These variations, which are only small and require delicate instruments to show them, can be divided into two quite distinct classes. In the first class are the regular diurnal and annual variations, while in the second are much larger irregular fluctuations which occur occasionally and which, when very large, are known as magnetic storms. While the main permanent magnetism of the earth appears to have its origin within the earth, these variations are due to currents very high above the earth's surface.

One of the simplest magnetic elements to measure is the declination, or the angle between the geographical and magnetic north. A sensitive compass needle can easily be made by suspending a bar magnet by a single thread so that it is quite free to turn in any direction. If a small mirror be attached to it and a beam of light reflected by the mirror on to a scale, very small movements of the magnet can be seen. With such an instrument it can be shown that on many days the magnet goes through a regular movement which is repeated each day, reaching a maximum in one direction in the morning and a maximum in the other direction in the afternoon, while it moves but little through the night. Such days are known as magnetically quiet days. The total movement of the magnet is quite small, being only about a sixth of a degree in summer and only about one-twentieth of a degree in winter in England. If other characteristics of the earth's magnetic field are measured, such as the total intensity of the field or the angle between its direction and a horizontal surface, the same type of effects will be observed.

On other days there will be pronounced irregular variations of the magnetic force which affect the whole world. These latter fluctuations are much stronger in polar regions than in low latitudes, and there is now little doubt that they owe their origin to streams of charged particles shot out from the sun. The reason that they are felt more in high latitudes is that the magnetic field of the earth deflects the charged particles so that they strike the earth only in the higher latitudes, where they produce a visible effect, namely, the aurora.

Both the regular and irregular variations of the earth's magnetic field are connected with sun spots. Sun spots are dark markings on the surface of the sun which can easily be seen with a small telescope, while a large spot may occasionally be seen with the eye. The exact nature of sun spots is at present unknown, but they indicate in some way the activity of the sun, and go through a fairly regular cycle of about 11 years length. Thus, in some years there may be a large number of spots so that nearly every day one or more spots can be seen. Then the number will decrease during the next

years, and about 6 years afterwards no spots may be seen for many days running. Later still the spots will become more frequent and in another 5 years or so will have reached their maximum. Sun spots are carried across the sun's disk as the sun rotates on its axis, so that a spot which lasts sufficiently long will reappear every 26 days, this being the time taken by the equatorial part of the sun to rotate, as seen from the earth.

The connection between the irregular variations of the earth's magnetism and sun spots is seen in the fact that magnetic disturbances tend to recur at intervals of 26 days. Also the number of magnetic disturbances increases during those years when there are many sun spots. Certain individual magnetic disturbances seem to be associated with definite spots.

The regular changes in the earth's magnetic field also show a connection with sun spots. Thus, the average amplitude of the regular

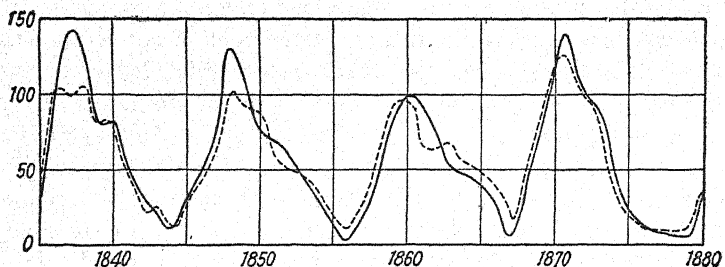

FIGURE 7.—Relation between terrestrial magnetism and sun spots.

The continuous line shows the changes in the mean annual sun-spot number, while the dotted line shows the mean annual range of the daily swing of the compass needle. The latter may be taken to indicate also the conductivity of the upper atmosphere. Note that the 11-year period in both cases is marked, but not quite regular. Note also the close connection between the two phenomena.

daily swing of the compass needle for any year is most closely associated with the average number of sun spots for that year. We believe that the regular diurnal magnetic variations are connected with changes in the conductivity of the upper air and that this conductivity is due to the action of the sun's ultraviolet light on the upper air, whereby free electrons are produced. There is a small lunar diurnal variation of the earth's magnetic field which is apparently due to tides set up by the moon in the upper air. These tides should have no effect on the magnetic field unless the air is a conductor, and it has been shown that during the night when sunlight is cut off, the lunar tides have no effect, their presence being seen during the hours of daylight.

Results from radio measurements.—While the study of terrestrial magnetism gave the first indication that the upper air was an electrical conductor, our knowledge has been rapidly extended in recent

years by the observations of radio waves. It would be impossible to send wireless signals to distant parts of the earth if the wireless waves were not bent round to follow the earth's surface. The fact that wireless waves are bent round the earth is due to the existence of the electrically conducting region at a great height, which bends these radio waves downward in much the same manner that the upper warm region bends the sound waves. If a very short signal be sent out from a transmitter, a neighboring receiver will receive the signal by the direct path along the ground and shortly afterward may receive another signal by means of waves which have traveled straight up into the atmosphere and have been reflected back again by the upper conducting region. Since we know how fast wireless waves travel, it is possible to measure to what height they have been before being reflected back again.

The conductivity of the upper atmosphere is due to the presence of free electrons, formed, as we have said, by ultraviolet light from the sun. The concentration of these electrons can also be found because it requires more electrons to reflect back a short-wave-length signal than a long-wave-length signal. If a series of tests are made in which the wave length of the signal is gradually reduced, we find that at first the height to which the signal goes before reflection, slowly increases. This is because it has to go somewhat higher before it reaches a place where there are enough electrons to reflect it, showing that the concentration of electrons increases with height. But as the wave length of the signal is still further reduced, something new is found, for, instead of the signal being reflected a little higher, it is now reflected at a very much greater height and no signals are reflected from the intermediate height. This shows that there are two regions where the concentration of electrons is high. The first is at a height of about 100 to 150 kilometers and the second from 200 to 400 kilometers, according to conditions.

Such experiments with radio waves show that the number of free electrons in the upper atmosphere—and hence its conductivity—varies greatly through the day. During the night the lower conducting layer (100 to 150 kilometers) is largely absent, since the electrons quickly attach themselves to air molecules and no more are formed.

About sunrise the number of electrons rapidly increases and remains large through the day. As would be expected, the number of electrons present during the daytime is greater in summer than in winter. The daily variations of the number of free electrons in the upper conducting region (200 to 400 kilometers) are less regular than those of the lower region. During the night the free electrons here also attach themselves to air molecules so that their number

decreases, but more slowly than those lower down because of the reduced density of the air. Shortly before sunrise on a winter day a radio signal may have to go to a height of 400 kilometers before it is reflected back. In such conditions signals of still shorter wavelength may not find enough free electrons at any height and consequently will not be reflected back at all.

While much of the conductivity of the upper atmosphere is due to electrons formed by the sun's ultraviolet light, the charged particles from the sun, which cause magnetic storms, also form free electrons. The electrons formed by this means are found largely at a height of a little above a hundred kilometers, i. e., at much the same level as the lower layer formed by sunlight. In the middle of the night when ultraviolet sunlight is cut off, a strongly conducting region may suddenly be formed at a height of about 100 kilometers at times of magnetic disturbance.

The charged particles which cause magnetic storms travel from the sun to the earth much more slowly than light, hence it has been possible, at the time of an eclipse, to establish definitely that ultraviolet light and not charged particles is responsible for most of the conductivity regularly present in both the 100 to 150 kilometer and probably also the 200 to 400 kilometer region, in temperate latitudes. In polar regions, as might be expected, the effect of charged particles is much more marked and much more frequent.

It has been suggested that the electrical conductivity of the upper atmosphere is dependent to some extent on the weather conditions at the earth's surface; also, that thunderstorms play an appreciable part. We are not yet, however, in a position to state anything very definite about this, and further observations are needed.

Aurorae.—While observations of the aurorae have, as yet, provided little additional information about the state of the upper atmosphere, they must be mentioned since they are clearly due to the same stream of charged particles which causes magnetic storms. The aurora is very closely related to magnetic storms, bright aurorae being usually seen at times of magnetic disturbance.

From the work of Professor Störmer in Norway and others, we now know accurately the heights of aurorae. The heights are measured by taking simultaneous photographs of the aurora from two distant stations. It is found that while the tops of the rays may go up to great heights—400 kilometers or more—there is a much sharper boundary at the bottom, at a height of about 100 kilometers. It will be remembered that radio measurements showed that the conductivity due to charged particles was most marked at just about this level.

THE NATURE OF THE COSMIC RADIATION[1]

By Thomas H. Johnson

Assistant Director of the Bartol Research Foundation of The Franklin Institute and Research Associate of the Carnegie Institution of Washington

[With 4 plates]

1. HUMAN VALUE OF COSMIC RAY INVESTIGATIONS

Scientific research projects divide themselves into two classes according to the human value of the results; those from which some new device or method develops, augmenting our comforts, conveniences, or abilities, and those resulting in new points of view. Values of the first type are evident in every phase of practical living. The second are not as generally appreciated, though the values are often more genuine.

It is not always possible at the outset to know into which class a particular search for the truth will fall. Oftentimes values of both types develop. But in the case of certain astronomical investigations, of which the study of cosmic radiation is typical, the philosophic interest is paramount. The total energy falling upon the earth's surface in the form of cosmic radiation is about one-thousandth of star light or one-billionth of sun light. Even if the cosmic ray energy were equal to sun light it would probably be an inferior source of power, for the extreme penetrating ability of the cosmic radiation prevents its concentration for conversion into useful forms of work.

2. METHODS OF INVESTIGATION

Although the cosmic ray intensity is minute when expressed in terms of total energy, single cosmic rays possess more energy than any other known form of radiation, and they are easily detected, one at a time. If we had suitable nerve responses we would be conscious of about 25 cosmic ray shots through some part of the body each second. The rays may be detected in several ways, all of which

[1] Lecture, Carnegie Institution of Washington, Washington, D. C., Mar. 12, 1935. Reprinted by permission from the Journal of the Franklin Institute, vol. 220, pages 41–67, July 1935.

depend upon the ability of a cosmic ray to ionize, or split apart, the electrical charges of the atoms of matter through which they pass.

If the air in a chamber is supersaturated with moisture the charged atomic fragments, or ions, act as centers of condensation for droplets of water and these may be photographed. Plate 1, figure 1, shows such a photograph of the ion trail left in the wake of a cosmic ray.

Another simple device for detecting ionizing radiations is the Geiger-Mueller counter, represented in figure 1. A metallic cylinder is placed in a glass tube, within which the air pressure is reduced to about a tenth of the normal atmosphere, and a fine wire is stretched along its axis. In operation the cylinder is charged negatively to 1,500 volts and, if a ray produces as much as a single ion within the cylinder, this is swept by the electric field toward the wire. As it approaches, the acceleration increases until the energy gained between encounters with atoms of the air causes it to ionize these at each successive collision. Each new ion becomes an ionizing agent and an avalanche resembling an electric spark is started. The flow of electric charge becomes great enough to be detected directly or it can be amplified and recorded on a suitable electric device.

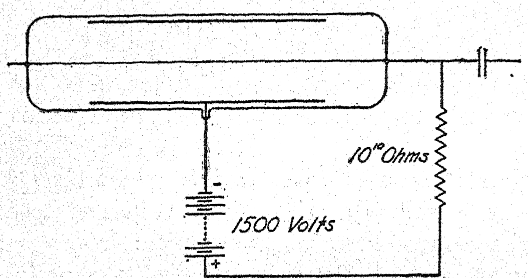

FIGURE 1.—Diagrammatic sketch of the Geiger-Mueller counter and its electrical connections.

When a small counter of this kind, 4 centimeters long and 1 centimeter in diameter, is connected to an amplifier and loudspeaker, about 20 clicks are heard in a minute. A radioactive substance placed near the tube can increase the count to several hundred a minute, each count indicating the passage of one ionizing ray. The radioactive radiations are well known and will not come into the discussion further. The subject of interest pertains to the 20 rays per minute indicated when all radioactive materials are removed.

These rays have been known to exist for 35 or 40 years but only in recent times have differences been recognized between them and the radioactive radiations.

One such difference of particular significance in the investigations is the ability of the residual radiation to excite avalanche discharges in several tubes at once. If two counters are connected in an appropriate electrical circuit the simultaneous discharges can be automatically selected from the others and recorded separately. In the case of two large counters whose individual discharge rates

are about 300 a minute, practically no simultaneous discharges occur when the tubes are separated, but if one counter tube is placed directly above the other such simultaneous discharges or "coincidences" are frequent. In the latter position single rays can pass through both tubes. The advantage of this arrangement for the cosmic ray measurements is that the radioactive radiations have no effect. Such rays, if of the penetrating gamma type, excite discharges only when they convert themselves into the nonpenetrating beta type within the counter cylinder. One gamma ray can never excite more than a single counter. The coincidence counters thus select the cosmic rays for their recording and, furthermore, they pick out only the rays which are coming from within a small range of directions.

A third method of investigation consists of measuring the current of ions produced directly by the cosmic rays in a vessel filled with gas. To increase the effect the vessel is usually filled to a high pressure and often the current measuring instrument is placed inside. Radioactive radiations can be eliminated, if necessary, by lead shields on the outside. These instruments, called electroscopes, have been used to a large extent in cosmic ray intensity surveys. Though extremely accurate and reliable they suffer a disadvantage in not being able to determine from what direction the rays are coming.

3. EVIDENCE THAT RAYS ARE OF COSMIC ORIGIN

Experiments with all three types of instrument have built up convincing proof that the rays are of cosmic origin. By rotating the line of two coincidence counters, the intensity of cosmic rays can be studied as a function of the direction. This directional distribution favors the vertical and very little intensity is incident from the horizontal. Most of the cosmic rays are coming down from above at steep angles. This type of angular distribution would be expected if the rays originate outside the atmosphere, for they would be absorbed at the low angles in proportion to their longer paths in the air. A source outside the earth was proposed as early as 1913 by Hess who carried apparatus in a balloon and found the intensity increasing with elevation. At a height of 4,300 meters four times as many rays strike a square centimeter of surface per second as at sea level, and a 300-fold increase over sea-level intensity has been found in the stratosphere. All evidence points to the regions beyond the atmosphere as the source of the cosmic radiation.

4. PROBLEMS FOR INVESTIGATION

What are these rays which come to us from the depths of cosmic space? How, where, and under what conditions are they produced?

What can they tell us of the conditions in other parts of the universe, both at their place of origin and in the interstellar spaces they traverse? What are the effects of their bombardment on our own planet? Many problems present themselves for investigation. The field is a new one to science and, like Aladdin, we wonder what new mysteries are about to be revealed. One must not be impatient, for the revelation is slow and involves many difficulties. Some progress, however, has already been made, particularly in regard to the problem of the nature of the radiation.

To understand what cosmic rays are, involves knowledge of their electrical charges, their masses, and their energies. These are the quantities which play the significant roles in determining the behavior of a ray. Are the rays electrically neutral or are they charged? If charged, are they positive or negative, and how much charge do they carry? How much inertia do the rays possess and do their masses correspond with any known particles? How much matter would have to be converted into energy in their production, or through what differences of electric potential would the rays have to fall to gain their energies? The questions are not only interesting in themselves, but their answers will be helpful clues in tracing down the places and processes of origination.

5. METHODS FOR ANALYSIS OF THE COSMIC RADIATION

With the technique in hand for detecting cosmic rays and measuring their intensity, methods of analysis have developed. For many years after their discovery the cosmic rays were commonly supposed to be photons, similar in character to the X-rays, the gamma rays, or the light rays. Experience had shown that rays of this type were more penetrating than corpuscular rays of equal energy and it was natural to assume that the extremely penetrating cosmic rays were also photons. Even on this assumption it was necessary to postulate energies far in excess of anything known, to account for their great depths of penetration through matter.

A more discriminating method for the analysis of radiation than that of the studies of penetrations consists in determining the deflection when the rays are passed through a magnetic field. If the ray carries an electric charge it constitutes an electric current and is subject to the same kind of force as is exerted on the wires of the armature of an electric motor. Under the action of this force charged rays may be bent into circular paths, the direction of curvature depending upon the sign of charge. Positive rays are curved oppositely to negative rays, and neutral rays pass through undeflected. Moreover, the radius of curvature determines the resistance

of the ray to the magnetic bending force. This property, which we may call the magnetic rigidity or, for brevity, the rigidity, depends upon the product of mass and velocity of the ray divided by the amount of its charge.

In the case of the cosmic radiation a magnetic analysis has been carried out, using the method of cloud-track photography, by Anderson in California, Kunze in Germany, and Blackett in England. A typical photograph of Anderson's is represented in plate 2, figure 1. A magnetic field of 12,000 gauss was applied to the cloud chamber and the ray was bent into a circular arc. The direction of bending shows that the ray is negative. From the radius of curvature it is found that the rigidity of this ray corresponds to a particle of the mass and charge of the electron and with a velocity such as would be gained by a fall through a difference of potential of 18 million volts. The expression "corresponds to" is used because other values of mass, charge, and velocity could give the same rigidity. That the ray is really an electron may be inferred from the fact that the track is a thin one. A proton of greater mass but of the same rigidity would have been moving more slowly. With more time to act upon the atoms along its path the track would have been denser. If the charge were greater, as in the case of the alpha particle represented in plate 2, figure 2, the track would have been very much denser. From all of the evidence it is possible to distinguish between the various kinds of rays, for the number of possibilities is small. In fact the different kinds of rays believed to exist are limited to those with small integral values (0, 1, 2, etc.) of both mass and charge, the respective units being the mass and charge of the proton. All of the combinations known to exist are contained in table 1. Those designated by (?) are anticipated but not known to exist. The table extends along the diagonal to the lower right, including the nuclei of the stable atoms.

TABLE 1.—*Table of elementary particles*

Mass	0	1	2	3	4
Charge (−)					
−1	Negatron (negative electron)	Negative Proton?			
0	Photon Neutrino?	Neutron	Double Neutron?		
+1	Positron (positive electron)	Proton (^{1}H nucleus)	Deuteron (^{2}H nucleus)	Triplon (^{3}H nucleus)	—
+2				Light alpha particle (^{3}He nucleus)	Alpha particle (^{4}He nucleus)

Because of the small number of entries in the table and because of the recognizable differences in the way rays of different charge and mass act upon matter, it is usually easy, except in the case of extremely high energy rays of equal charge, to identify the ray by its track. Practically all of the rays listed have been found associated with the cosmic radiation.

We know, however, that many of the rays found in the cloud chamber are secondaries produced from surrounding matter and there is difficulty in distinguishing these from the primary cosmic rays. Occasionally clusters of rays or "showers", such as represented in plate 1, figure 2, are found, apparently emanating from one or two points in surrounding material, as though they had been generated there by the impact of some very energetic primary ray. Even if the point of origin of a shower should chance to occur within the gas of the chamber and the ray generating it could be photographed, there would still be uncertainty whether it were not just another secondary from some previous shower. The presence of matter between us and the source of the radiation confuses the problem, and if we are to know what the primary cosmic rays are, we must have an apparatus which operates in the space beyond the atmosphere.

The proposal seems fantastic, but actually the earth's magnetic field constitutes such an apparatus. The confusion of secondaries begins at the top of the atmosphere, only a few miles above the surface, but the bending force of the magnetic field begins to curve the primary rays at distances of thousands of miles. In determining the amount of such curvature, for calculation of rigidities, it is impossible to trace out the paths of single rays as was done in the cloud chamber analysis, for observations are limited to those which can be made on the earth's surface and within the atmosphere. But it will appear that this is no handicap, for the variations of intensity with changes of direction and position on the earth's surface give the equivalent information for the determination of the rigidity, and absorption in the atmosphere contributes the supplementary evidence, analogous to the track densities, for further identification of the type of ray. The two methods are equivalent, except that the earth-magnetic analysis concerns the primary rays alone.

6. SIMPLIFIED ANALOGY OF THE EARTH-MAGNETIC ANALYSIS

The relations between the rigidities of the primary rays and the measured intensities are complex and mathematical, but without going into the rigorous theory all of the essential points can be made clear by a simple analogy. The complexity of the real problem is due entirely to the peculiar form of the earth's field and if we consider an imaginary field of uniform extent and intensity the problem is simple indeed.

Referring to figure 2, we assume that an observer can make measurements of intensity from any direction and at any point in the lower plane. This plane is analogous to the earth's surface, and it prevents radiation coming up from below. Between the upper and lower planes a magnetic field has the direction of the arrow and is uniform over any section parallel to the front of the diagram, but is of increasing strength toward the back. The line $O\ O''$ is analogous to a magnetic meridian line in the northern hemisphere of the earth with the point O'' near the Equator where the earth's horizontal field is strongest. Thus the right side of the diagram corresponds to the west.

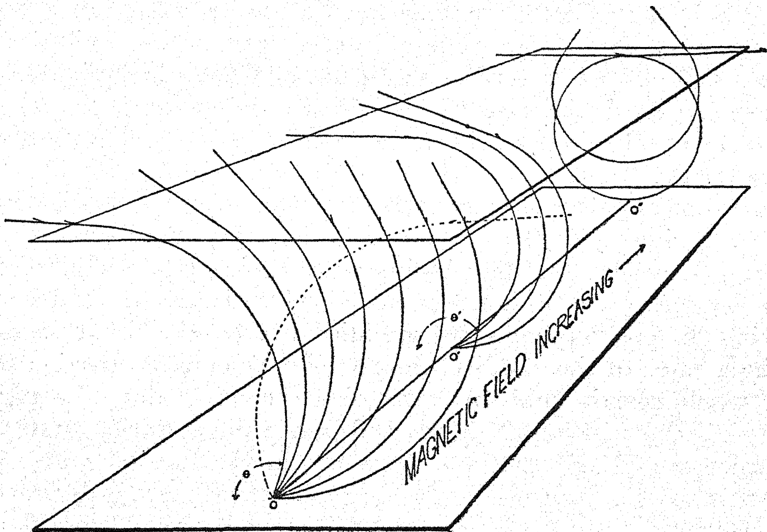

FIGURE 2.—Intuitive illustration of the essential elements in the earth magnetic analysis of the cosmic radiation.

The essential point in the analysis is the realization that the path of a ray in the region of the magnetic field is a circle, the radius of which depends upon the strength of the field and the rigidity of the ray. Rays are incident uniformly from all angles in the upper half of space but the observed distribution in the lower plane is altered. Positive rays of a particular rigidity, corresponding to the curvature of the paths represented, and incident from the left horizon reach the station O from some angle θ, or from the more inclined angle θ' at O' where the stronger field produces more curvature. At the point O'', where the field is still stronger, the same radiation may not be able to reach the observer at all. Referring again to station O, the angular region to the left of θ can be illuminated only by rays of higher rigidity than those which cut off at angle θ,

whereas these rays uniformly illuminate the region to the right. If no rays, other than those of the curvatures represented in the diagram, were present in the primary radiation, the observer would find a sharp cut-off in the intensity at θ. By measuring this cut-off angle, knowing the strength and extent of the field, the sign of charge and the rigidity can be determined. If rays are bent in the opposite direction, as indicated by the dotted orbit, the region of low intensity lies on the opposite side of the vertical. Thus, both the rigidity and the sign of charge are determined by the angle θ.

In case the radiation were not of a single rigidity, but had some kind of a distribution over all values, the sharp cut-off would be replaced by a gradually changing intensity. The difference between intensities at two angles would be due to rays whose rigidities lie within the range between the two cut-off values. If positives and negatives were both present, the intensity difference at two angles would be equal to the excess in the number of charged rays of one sign over the other.

Thus the angular measurements determine the distribution with respect to rigidity of the excess of one sign of charged ray over the other. To resolve the distribution of each sign separately angular intensity measurements must be combined with results obtained by varying the position along the meridian line $O\ O''$. In the case of a single value of the rigidity, the intensity from any direction such as θ' would remain uniform, as the observer moves along the meridian, until the position O' is reached where the intensity from this direction would fall suddenly to zero. In the case of a distribution this sudden drop would also be replaced by a gradually changing intensity and, in this case, the difference between intensities in any two positions is due to rays of both signs of charge, in proportion to their numbers, in the ranges of rigidity determined by the cut-off angle θ' at the two positions. Thus, this type of measurement determines the distribution with respect to rigidity of the sum of the positive and negative rays together. Combining this result with the distribution of the excess of positives over negatives, we can discover the distribution of each component separately.

A change of intensity with position along the meridian can also be recorded by an apparatus which measures intensities from all directions, for example the electroscope, but the analysis of the distribution from this type of measurement is not as straightforward for the reason that the gradual change of intensity due to the changing angle of cut-off cannot be distinguished from the changing intensity which takes place at each angle due to the distribution of rigidities.

7. THE PROBLEM OF THE REAL EARTH

The only difference between the simplified problem and the problem of the real earth is in regard to the numerical relationship between any value of the rigidity and the angle at which it cuts off, for any latitude. In the case of the real earth Størmer, and Lemaitre and Vallarta have determined these angles by solution of the mathematical equations of motion of the rays in the field of the magnetic doublet of the earth. The results are illustrated in figure 3. The areas of the sky, represented in white, give the angles from which rays of the rigidity of a 10-billion-volt positive electron can reach the observer at the various latitudes. On the Equator the bending force of the field is greatest, and rays of this rigidity almost miss the earth completely. There is but a small white area on the western horizon. To reach the earth from all directions at the Equator, rays must have the rigidity of a 60-billion-volt electron. In northern Mexico, on the other hand, the 10-billion-volt electrons can come in from all directions. Positive rays of low rigidity appear first on the western horizon, negatives on the eastern horizon.

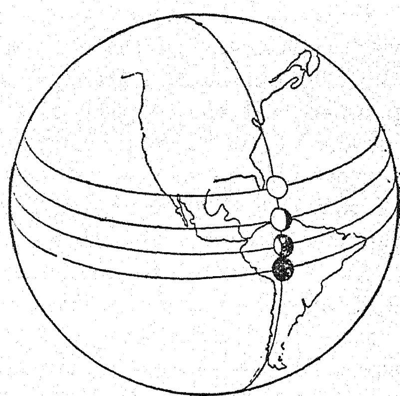

FIGURE 3.—Regions of the sky, represented in white, illuminated by rays of rigidity corresponding to 10-billion-volt positive electrons.

8. THE EXPERIMENTAL MEASUREMENTS OF LATITUDE-INTENSITY VARIATIONS

The first indication of an effect of the earth's magnetic field in altering the cosmic ray intensity distribution was found in 1928 by Clay. From his measurements the intensity seemed to be lower in equatorial latitudes. Compton's world survey begun in 1932, has placed the result on a firm experimental basis and has shown that the intensity depends upon geomagnetic and not upon geographic latitude. The lower intensity at the Equator is thus caused by the magnetic field and not by some other systematically varying quantity such as temperature. Very careful studies of these variations by Millikan and his associates have resulted in accurate data, particularly in the case of automatically recorded sea-level measurements. In all three cases electroscopes have been used, and the results pertain to the average of the effects from all directions. Some directionally selective measurements, ideally more favorable for the analysis, have been made with coincidence counters mounted on shipboard by Auger and Leprince-Ringuet.

Compton's results are typical, and are particularly significant because of the wide range of latitudes, elevations, and longitudes covered. Higher intensities occur at high latitudes and the increase with respect to the value at the Equator is 14 percent at sea level, 22 percent at an elevation of 2,200 meters, and 33 percent at 4,300 meters.

9. THE SURVEY OF ANGULAR DISTRIBUTIONS

Following the discovery by the writer and J. C. Street of an east-west asymmetry of the coincidences of alined counters on Mount Washington, N. H., in 1932, a survey for the study of this effect was planned with the cooperation of the Carnegie Institution of Washington and was begun early in 1933. Up to the present time the survey includes measurements at the stations indicated on the map of figure 4. Confirmatory results of significance have also been reported by numerous other observers.

The magnetic directional effect is manifest as an asymmetry, or a difference of intensities from eastern and western azimuths at the same zenith angle. The magnitude of the asymmetry is conveniently expressed as the ratio of the intensity difference to the average intensity for the two directions. In this form it is equal to the intensity of the unbalanced charged component in the range of rigidities determined by the cut-off values for the two angles, this intensity being expressed as the fraction due to this component of the total number of coincidence counts. Only the relative intensities are involved, and the measurements do not have to rely upon the calibration of the sensitivity of the instrument. Changes of sensitivity during a measurement, however, must be avoided. Because of the rapid change of intensity with zenith angle, caused by atmospheric absorption, this angle must be kept accurately the same in both azimuths. With a system of frequent rotations automatically controlled by clock works, about an accurately placed vertical axis, and with readings taken automatically, the problem of keeping a constant sensitivity under field conditions has been largely overcome and intensity ratios have been determined with an accuracy approaching the theoretical limit of the statistical fluctuations in the total number of rays counted. In many instances intensity differences of the order of 10 percent have been measured with an error of less than 1 percent. The apparatus which has been developed for this purpose is represented in plate 3.

The results of the asymmetry survey are combined in figure 5. For each station the asymmetry, defined as above, is plotted against zenith angle. The ordinates are thus equal to the unbalanced charged component in the range of rigidities determined by the correspond-

ing zenith angles. From right to left the stations are arranged in the order of increasing elevation and the rows are in the order of the geomagnetic latitudes. In every case western intensities are greater, though the amount of the excess varies widely with zenith

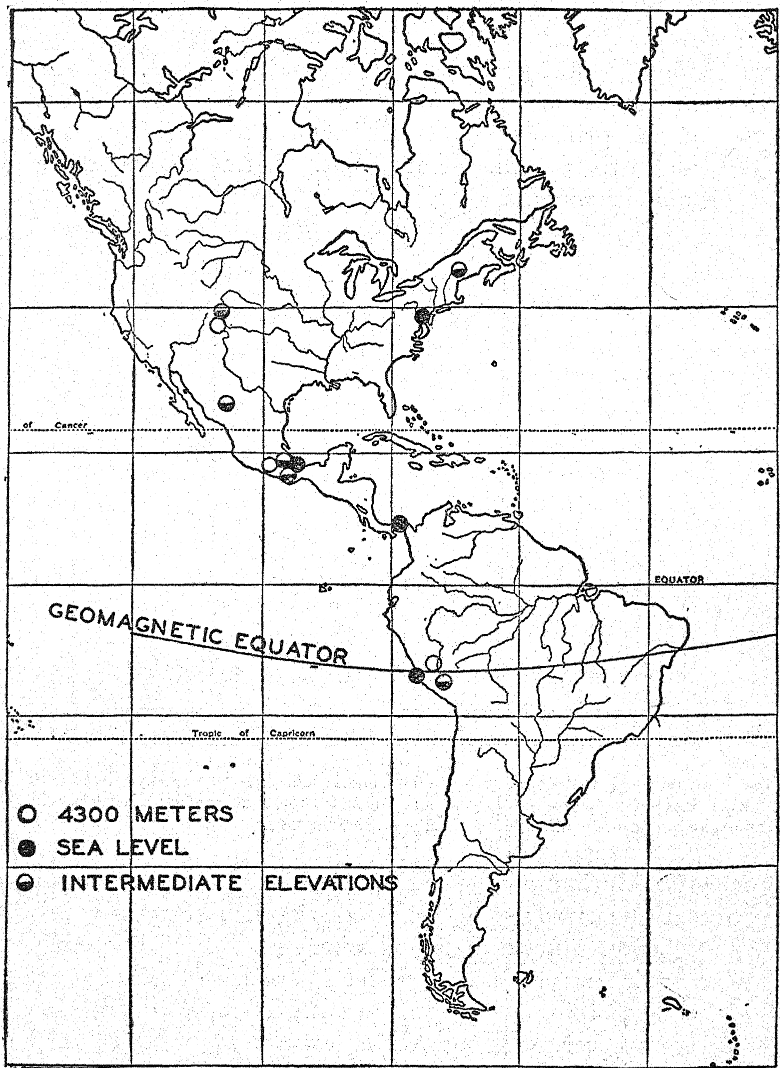

FIGURE 4.—Stations where directional measurements have been made.

angles, latitude, and elevation. Progressing toward the Equator, there is a definite trend toward higher asymmetries, and at each latitude asymmetries are greater at the higher elevations. At each station the asymmetry increases with zenith angle to a maximum value at 50° or 60° and thence falls off again toward the hori-

zon. Though the accuracies and the range of stations are not all that are desired, the data present good indications of the general characteristics and the magnitudes of the effect.

10. ANALYSIS OF THE COSMIC RADIATION

With the results of the directional measurements and those of the variations of total intensity with latitude, together with the calculations of the cut-off angles, we are in position to make a tentative analysis of the primary cosmic radiation. The method of attack and the results to be achieved are clearly before us, but the course is not without its pitfalls.

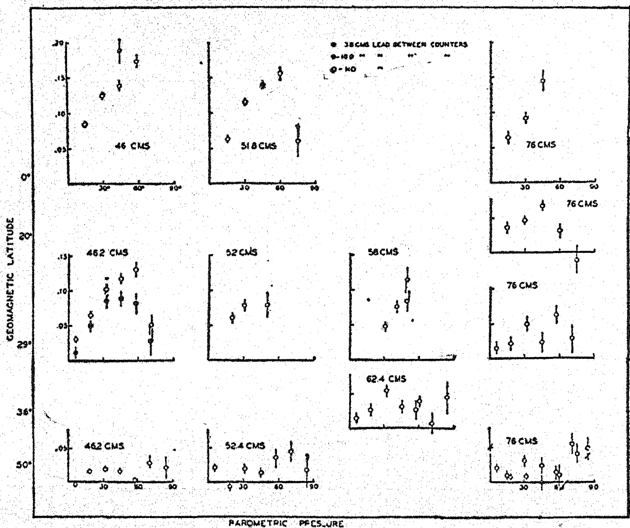

FIGURE 5.—Combined results of the measurements of east-west asymmetries. Ratio of east-west intensity difference to average intensity plotted against zenith angle. Stations arranged in order of their latitudes and elevations.

Størmer's solution of the cut-off angles is simple in form and ready for application, but it fails to distinguish between rays which are coming from infinite distances where sources of radiation exist and those which might have described closed orbits in the vicinity of the earth had there been sources of radiation near at hand. The latter orbits are vacant and must be left out of account. Lemaitre and Vallarta have studied these orbits and find that they would illuminate a range of angles just inside the cut-off limit as it is given by the simple Størmer theory. It is also shown that within this range of angles no infinite orbits reach the observer, and hence it is only necessary to make a correction to the cut-off angle in taking account of the vacant closed orbits. With this refinement of the theory, the angles illuminated by rays of a particular rigidity cover

wider areas of the sky on the equatorial side of the east-west vertical plane, and a north-south asymmetry would be expected. Measurements in Mexico, represented in figure 6, show greater intensities from the south and confirm this detail of the calculation.

On the basis of Lemaitre and Vallarta's first estimates of the true cut-off angles of infinite orbits, the experimental results led to the tentative conclusion that the primary radiation was practically all positive, and nearly uniformly distributed with respect to rigidity. Recent investigations by the same authors, in collaboration with Bouchaert have resulted in more accurate determinations of the true cut-off angles in the range of latitudes from the Equator to 20°, but the theoretical work is not yet complete for higher latitudes.

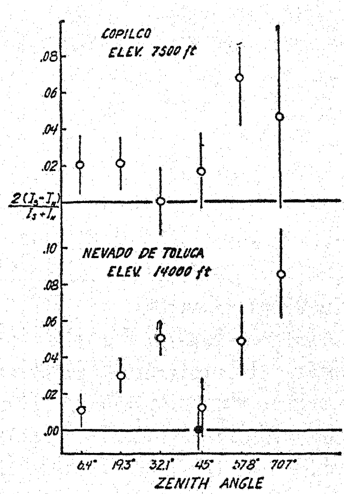

FIGURE 6.—North-south asymmetry of the cosmic ray intensity in Mexico, latitude 29°, elevation 4,300 meters.

Without further consideration it is clear from the western excess of intensity that much of the charged component consists of positive rays unbalanced by negatives. Analysis of the asymmetry measurements in the equatorial zone shows that 14.2 percent of the intensity at 4,300 meters is due to positives unbalanced by negatives in the range of rigidities below that which cuts off in the east. At the same elevation in Panama 16.9 percent of the intensity is due to radiation below the same limit of rigidity and similarly defined. The higher value for Panama is due to the slight eastward shift of cut-off angles for each rigidity and the inclusion of lower rigidities from the west. The difference in these figures (16.9% − 14.2% = 2.7%) is the change of the total intensity in this range of latitude which can be accounted for by unbalanced positive radiation. If the figure should agree with the measured change of intensity we could conclude that all of the latitude effect in this range can be accounted for by positives and that there is no negative component in this range of rigidity, contributing to the intensity at that elevation. Because of the absence of high mountains in Panama, accurate measurements of the latitude effect are lacking but the airplane measurements of Bowen, Millikan, and Neher show that the change of intensity in this range is small and probably does not exceed 4 or 5 percent. If the latter value is chosen as an upper limit, the difference between 5 percent and the 2.7 percent accounted for by unbalanced positives, must be accounted for by a balanced component of positives and negatives in equal numbers. Thus the

total negative component would have an upper limit of one-quarter of the total charged component. At sea level the excellent measurements of Millikan and Neher conspire toward a more conclusive analysis. At the equator the asymmetry shows that 10.4 percent of the sea-level intensity is from unbalanced positives. In Panama the figure is 12 percent. The difference, 1.6 percent, is the amount of latitude effect which can be accounted for by the unbalanced positives. This agrees with the average of Millikan and Neher's measurements of the total latitude effect, and it is concluded that negatives in the corresponding range of rigidity make no appreciable contribution to the sea-level intensity. This estimate is based upon the asymmetry measurements in Panama. If those at the Equator had been used instead, a larger latitude effect than that found would have been expected. Theory indicates no important differences between the asymmetries at the Equator and in Panama, and the latter measurements appear to be the more reliable on the basis of the probable errors.

For the analysis of rays of lower rigidity the measurements in higher latitudes are ready and awaiting the completion of the accurate theoretical calculations of cut-off angles. Higher rigidities, on the other hand, can never be analyzed by this method, as the earth's field is too weak.

Lower limits for the intensity in high latitudes of the entire charged component, positives and negatives combined, can be given without further delay. For this purpose it is only necessary to add the unbalanced positive component at the Equator to the measured values of the latitude effect. Expressed in terms of the total intensity at the Equator, at least 16 percent of the sea-level intensity and 30 percent of the intensity at 4,300 meters in latitudes above 50° is due to charged primaries. These figures represent lower limits from two points of view. In the first place the correction for possible negatives at the equator has not been taken into account, though it has been shown this is not necessary at sea level. The more important point is that much of the unanalyzed intensity at the Equator may also be due to charged rays of higher rigidities. It might well be argued from similarities in the absorption that the unresolved equatorial radiation is of the same character as the radiation known to be charged, but this type of reasoning is obviously less reliable than that used in the above analysis.

Now comes the question of what these unbalanced positive rays are: Table 1 suggests three possibilities. The first is the positive electron, a particle of very nearly zero mass and unit positive charge. Rays of this type are often produced when high energy gamma rays collide with atomic nuclei, and they are also generated in certain

types of spontaneous nuclear disintegrations. Though considerably more rare than their negative counterpart, they could possibly be present in the cosmic radiation. The second possibility is the positive proton, the nucleus of the more common form of hydrogen. These occur in large numbers on stars and in the interstellar regions and are very likely candidates. This possibility would also include the mass 2 and the mass 3 hydrogen nuclei which occur in certain small proportions with the ordinary hydrogen. The third possibility is the alpha particle or helium nucleus, which also occurs abundantly throughout the universe. Other heavier nuclei might also be included in this class. Their multiple charges and the consequent rapid loss of energy in traversing matter would seem to put these particles out of the picture as far as the sea-level intensity is concerned, though they might well contribute to the intensity in the upper atmosphere. In fact alpha particles have been proposed by Compton as an explanation of some of the radiation observed in the stratosphere. At sea level and up to the tops of mountains, the principle candidates for the cosmic rays are thus the proton and the positive electron.

If the rays are protons, the component observed at the Equator in the asymmetrical band at 30° from the vertical, lies in the range of energies from 11 to 20 billion volts. If the rays are positive electrons the energies extend from 12 to 21 billion volts. The range is outside the limits of previous experience, and it is necessary to rely upon the predictions of untested theories for the final identification of these rays from their absorption characteristics. The test is difficult because the theories show on quite general grounds that rays of equal charges but different masses behave nearly alike if the energy is large compared with the energy equivalent of the masses. The mass of the proton is equivalent to 1 billion electron volts and the lighter electron is equivalent to a half million electron volts. Both are small compared with cosmic ray energies. Theoretically the two kinds of rays should be absorbed by matter nearly alike. For the process of the excitation of photon rays by collisions with nuclei, however, the difference in mass may be significant, and there are reasons for expecting the electron with its smaller mass to excite photons more readily than the proton. To the extent that radiation losses are important ways for rays to lose energy, the protons should be the more penetrating.

At this stage in the analysis it would be extremely helpful to find a method of selecting one type of ray to the exclusion of the other, and if photon excitation is a unique characteristic of electron rays, an arrangement of apparatus, sensitive only to photons, would accomplish the desired end. Recent studies of the shower phenomena,

illustrated in plate 1, figure 2, seem to present such a possibility. Showers may be recorded to the exclusion of all other rays if use is made of their divergence in angle from the point of origin. Three counters arranged in a triangle and surmounted by a block of lead record coincidences only when a shower is produced in the lead. Several investigations have shown that the shower particles are generated in the lead by impact of a specific form of radiation, probably photons. If these photons are generated by primary electrons, as the theory indicates, and not by protons, the showers can be used as a measure of the electrons to the exclusion of the protons. During the directional distribution survey, showers were also studied in relation to changes of latitude, elevation, and direction, and the results are suggestive of electron primaries. It was found that the showers increase more rapidly with elevation than the total radiation, though in this respect they cannot be definitely distinguished from the unbalanced positive component which gives rise to the asymmetry. In fact the results at first suggested that the showers were closely associated with the positive component. Measurements in Mexico of the dependence of shower intensities on azimuth have now shown that this is not the case. Using an arrangement of counters illustrated in figure 7, shower intensities from the east and west were compared and the results showed almost no asymmetry. Latitude intensity variations of this component on the other hand have proved that the showers are caused by electrically charged primaries. There is only one conclusion. The primaries which produce the showers consist of equal numbers of positive and negative rays. Until there is more evidence for the existence of the negative proton, and in view of the ability of these rays to produce the shower-generating photons, we must regard this component of the primary radiation as an electron component. The equality in number of the positives and negatives is also agreeable to this view for the cloud-chamber experiments of Anderson have shown that electrons often appear as paired positives and negatives. In spite of the evidence that much of the primary charged component is positive, there is still place to fit in a small balanced component of positives and negatives, particularly at high elevations. It may also be true that as far as the effects recorded by aligned counters is concerned the electron component is quite insignificant.

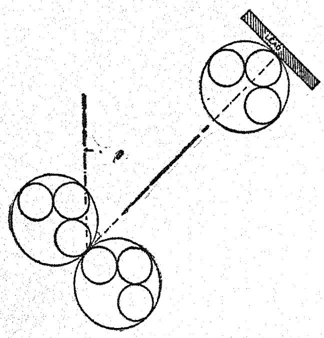

FIGURE 7.—Arrangement of three counters and a lead block for detecting cosmic-ray showers due to primary rays from particular directions.

Having identified a component which is probably electronic and whose properties are different from those of the unbalanced positive component, the only remaining possibility for the latter is the proton, the nucleus of the hydrogen atom.

11. THE SOURCE OF THE COSMIC RADIATION

The existence of an intense unbalanced positive component suggests that we look for electric fields as the source of cosmic-ray energies. Accustomed as we are to electrical displays during thunderstorms and volcanic eruptions, it is easy to imagine similar processes taking place on stars. Negatively charged clouds of dust or condensed vapor, high above the surface of a star could draw out positively charged atomic ions from its surface or upper atmosphere and project them, like the beam of a cathode-ray tube, into cosmic space. Nuclei of helium and hydrogen atoms, the principal constituents of the stellar atmosphere, would thus become the cosmic rays. During their passage through interstellar space these rays would encounter small quantities of matter and secondary rays would be generated. The secondaries could constitute the positive and negative electron component of what appears to us to be the primary radiation. If the picture is correct, one would also expect to find photons which would have been generated in a similar way in the interstellar spaces.

The secondary hypothesis of the origin of the balanced electron component raises the possibility of using its intensity as a measure of the total amount of matter in the space which the rays have traversed from their point of origin. Experience regarding generation of secondary cosmic rays requires the choice of 10 grams per cm^2 as a lower limit for the amount of matter within which an observable electron component could be produced. This lower limit of matter can be translated into a lower limit of distance from the source for the change in color of distant stars gives a means of estimating the density of matter in interstellar space. Using Becker's estimate of 0.4×10^{-26} grams per cc, it results that distances of the order of from 1 to 10 billion light-years would have to be traversed before the requisite amount of material could be encountered. It is interesting that these figures are of the order of the diameter of the expanding universe as deduced from the red shift and are consistent with the idea that our principal sources of cosmic radiation are the extragalactic nebulae which are uniformly distributed throughout space.

Such speculations would lead to the conclusion that cosmic rays are of the same intensity throughout intergalactic space as here within our galaxy, and if this is the case, the total energy in the

universe in this form exceeds that of starlight. Thus, any theory of the universe which leaves cosmic radiation out of consideration may fail to include an important element.

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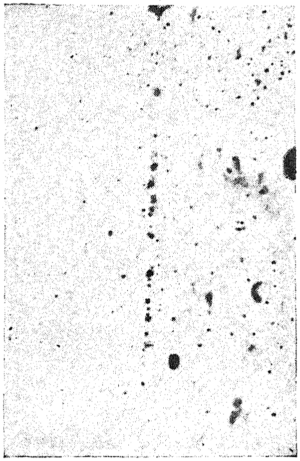
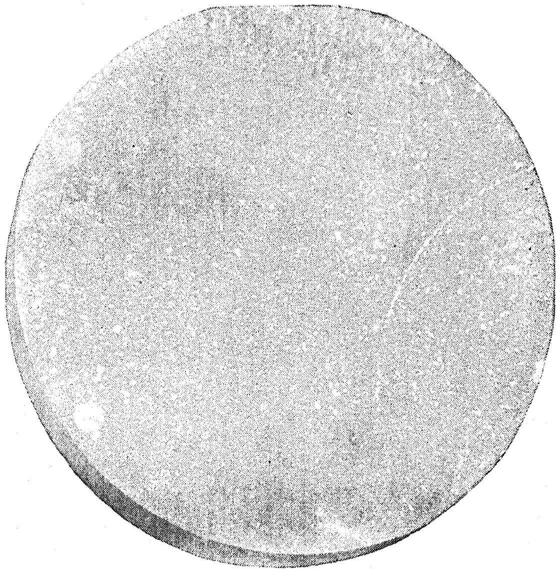


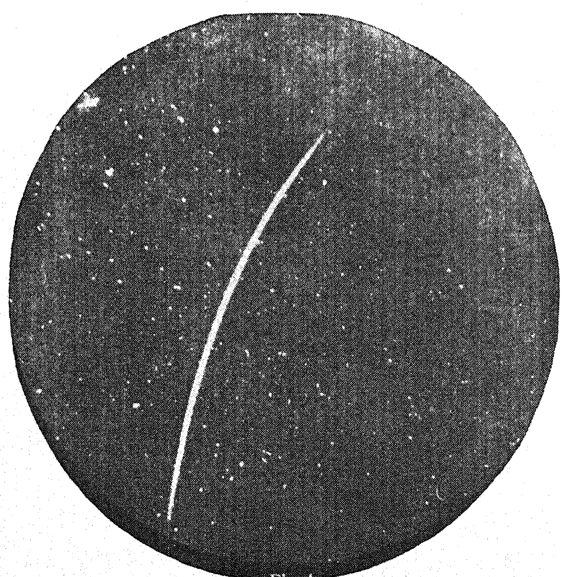
1. The cloud track of a cosmic ray, consisting of a row of water droplets condensed upon air molecules which have been ionized by the ray.

2. A cosmic ray "shower" photographed by Blackett and Occhialini. The existence of secondary rays such as these invalidate the use of the cloud chamber as a means of analyzing the *primary* cosmic rays. (Proceedings of the Royal Society.)



Physical Review.

1. Cloud photograph by Anderson of an 18-million volt negative electron curved by a magnetic field of 12,000 gauss. The direction and amount of the curvature and the density of the track are data useful in determining what the ray is.



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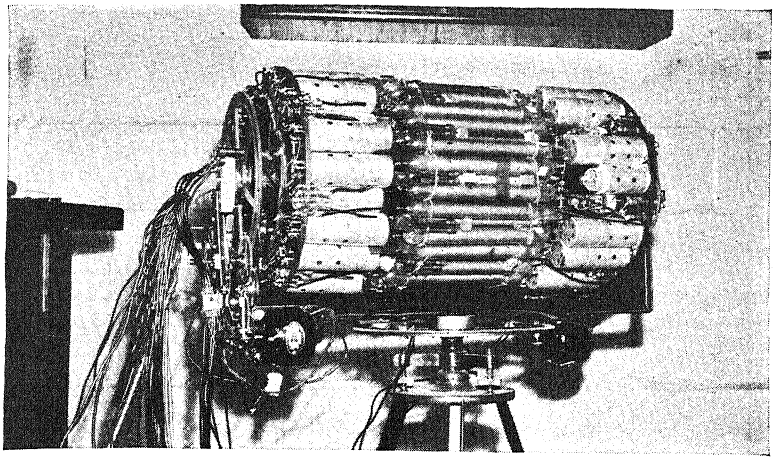
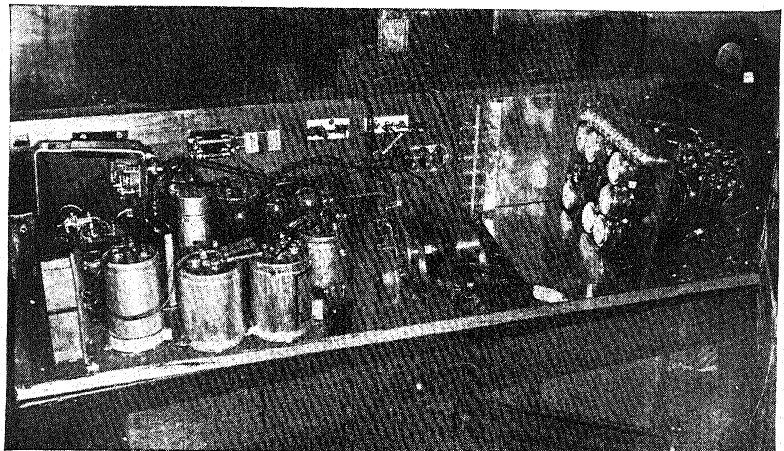
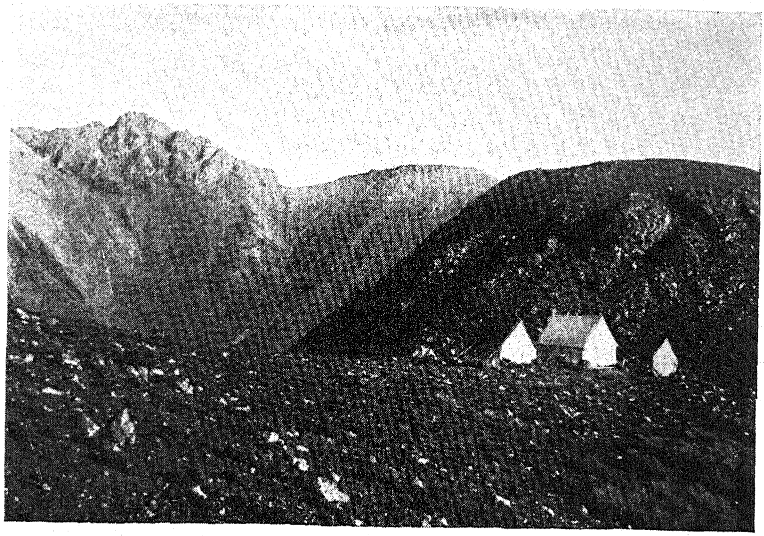
2. Track of an alpha particle by Anderson illustrating the greater density resulting from the higher charge and mass as compared with that of the electron of plate 2, figure 1.



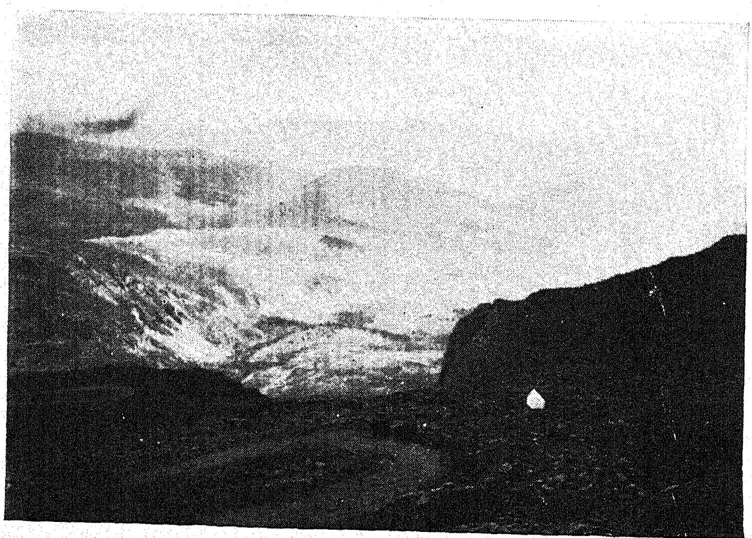
Counters and amplifiers.



2. Multidirectional cosmic ray meter for simultaneously comparing intensities in seven zenith angles and two azimuths. The operation is automatic with readings taken photographically on 16-millimeter cinema film.



1. Cosmic ray station on the summit of Nevado de Toluca in Mexico, elevation 4,300 meters.



2. Cosmic ray station on the summit of Mount Evans in Colorado, elevation 4,300 meters.

WHAT IS ELECTRICITY?[1,2]

By Paul R. Heyl
National Bureau of Standards

I trust that there is no one so optimistic as to suppose that because I have asked this question I am going to answer it, nor so pessimistic as to fear that because I have asked a question which I cannot answer I can offer you nothing but platitudes. I believe it possible in this case to avoid both Scylla and Charybdis.

This question, said the late Prof. John Trowbridge,[3] of Harvard University, is often asked as though it were capable of a short and lucid answer which might be understood by any person of liberal education. Many answers have been given, but it is interesting to note that the more definite and confident the answer the older it is, and that as we ascend the ladder of time toward the present day such answers as we encounter are less definite and more cautious.

It will be interesting to review, perhaps rather briefly, the ideas which have been held at various times as to the nature of electricity, and then, looking over the wealth of physical discovery which has been amassed in the past 40 years, to endeavor to select from it such facts as may be of importance in guiding and controlling future speculation on this question; for though such speculation has been at a minimum, if not a standstill, during the twentieth century, it will doubtless revive again. Speculation, or, as it has been otherwise termed, "apt conjecture, followed by careful verification", has been behind much of the advance of science. Such was the method of Faraday and of Darwin. The conjectures of the ancients, having little in the way of observed fact to guide them, might range far and wide, and had small heuristic value, but with the growth of experiment the range of conjecture has continually narrowed and its value as an aid to further progress has steadily increased.

The beginning of our knowledge of electricity is lost in the mists of antiquity. What we can recover of it is excellently told by Park

[1] Publication approved by the Director of the National Bureau of Standards of the United States Department of Commerce. Reprinted by permission from Journal of the Washington Academy of Sciences, vol. 25, no. 5, May 15, 1935.

[2] This is the fifth of the Joseph Henry Lectures of the Philosophical Society presented March 30, 1935, in honor of the first president of the Philosophical Society.

[3] Trowbridge, What is electricity? Kegan Paul, Trench, Trubner & Co., London, 1897.

Benjamin in his history, The Intellectual Rise in Electricity.[4] It is customary to credit Thales (600 B. C.) with the first observation of the attractive power of rubbed amber, but Benjamin shows that amber was widely known among the ancients for centuries before Thales. Beads of amber have been found in the ancient lake dwellings of Europe, in the royal tombs at Mycenae (2000 B. C), and throughout northern Italy. The identity in chemical composition of these relics with the amber of the Baltic Sea coast is significant of the esteem in which this substance was held and of the distance over which it was thought worth while to bring it. The golden glow of the polished beads suggested the beaming sun, called by Homer ἠλέκτωρ, which doubtless gave rise to the Greek name for amber, ἤλεκτρον.

It is incredible, as Benjamin points out, that this widespread acquaintance of the ancients with amber should have existed so long without its electrical property being often noticed. It is probable that Thales but shared the knowledge of his time in this respect, for his acquaintance with the things of Nature in general was such as to enable him to make the first recorded prediction of an eclipse of the sun. Thales left no writings of his own, and all we know of him we have learned from those who lived several centuries later.

It appears from these authorities that the ancients regarded electricity as a soul or spirit resident in an otherwise lifeless substance. This was in harmony with the prevailing thought of the times, which regarded all motion as evidence of life. The air was inanimate, but the wind was the breath of Aeolus; the waves of the sea were excited by the wrathful strokes of Neptune's trident; the lightning was the thunderbolt of Zeus. This animistic explanation of the nature of electricity was simple and definite enough to be understood by anyone and lasted for several millenniums—in fact until the revival of learning and the growth of experimental science supplied material upon which to base a rival theory.

We are helped to realize this animistic point of view when we read in a translator's footnote to Gilbert's book on the magnet[5] that a certain ancient physician recommended the administration of doses of powdered lodestone in cases of estrangement between husbands and wives. Given the premises of the time, such a conclusion was perfectly logical. It was obvious that the patients exhibited a deficiency of a certain spiritual element which was found in the lodestone, and the administration of that medicine followed as naturally as a modern prescription of cod-liver oil because of its vitamin content.

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[4] Longmans, Green & Co., London, 1895.

[5] Translation by P. Fleury Mottelay, p. 56, John Wiley & Sons, New York, 1893.

It was the middle of the sixteenth century before the next answer on record was given to the question: What is electricity? This answer came from Cardan,[6] whose name is familiar to mathematicians (perhaps more so than it deserves to be). Cardan was the originator of the fluid theory of electricity which held the stage in one form or another for over 3 centuries, and survives today in popular parlance in the term "the electric fluid", or, still more colloquially, "the juice." Cardan passed from the spiritual to the material in his explanation, which was that amber "has a fatty and glutinous humor which, being emitted, the dry object desiring to absorb it is moved towards its source, like fire to its pasture; and since the amber is strongly rubbed, it draws the more because of its heat."[7]

In this last sentence we see the influence of Cardan's profession. He was, among other things, a physician, and was accustomed to warm the cupping glass in drawing blood from his patients. The laws of pneumatics were not yet understood at that time, and it was generally supposed that the cupping glass acted because of its heat.

The fact that this "fatty and glutinous humor" was intangible and invisible seems to have caused Cardan no embarrassment. We may perhaps view this the more charitably when we think of the contradictory attributes that later scientists have found it convenient to assign to the luminiferous ether.

The year 1551, in which Cardan published this theory, may be taken as marking the end of the first era, in which electricity was regarded as a soul or spirit. Its beginning goes back beyond recorded history.

The concept of electricity as a material substance contained in certain bodies known as electrics was strengthened by the experiments of Gilbert (1600), who showed that many substances besides amber were to be included in this class, but the full development of the fluid theory of electricity did not come until the middle of the eighteenth century. In the meantime, von Guericke (1672) had invented his sulphur globe electrical machine, which made electrical experimentation easy on a large scale. With the facilities thus placed at his disposal he discovered electrical conduction and electrostatic repulsion, the latter destined to be a phenomenon of prime importance in later speculation on the nature of electricity.

In the eighteenth century development of the fluid theory two names are prominent, those of Du Fay and Franklin, each typifying a separate trend in theory.

Du Fay's experiments (1733 and later) chronologically preceded those of Franklin. His most important discovery was that glass

[6] Cardan, De subtilitate, lib. 21, Paris, 1551.
[7] Benjamin, Park, op. cit., p. 248.

when rubbed behaved in one respect quite differently from amber; a bit of gold leaf excited by contact with the glass tube is then repelled by the glass but attracted by excited amber. "And this", said Du Fay, "leads me to conclude that there are perhaps two different electricities." These he distinguished accordingly as vitreous and resinous, and laid down the law that like electricities repel each other and unlike attract.

To explain the same phenomenon Franklin (1747) postulated a single electric fluid of which all bodies were normally full. If a body acquired more than this normal amount he called it plus, or positively electrified, and if its charge was less than normal, minus, or negatively electrified.

Franklin's hypothesis had simplicity in its favor; it required one less assumption than that of Du Fay. In this respect it obeyed more closely the rule laid down by Newton:

> We are to admit no more causes of natural things, than such as are both true and sufficient to explain their appearances * * * for Nature is pleas'd with simplicity and affects not the pomp of superfluous causes.[8]

This simplicity of Franklin's hypothesis, added to the reputation which he himself rapidly attained in scientific circles, gave the one-fluid theory an advantage over its competitor for the time being, but a serious theoretical objection was soon raised against it. Since on this theory a negative charge meant a deficiency of electric fluid, there must be a limiting value of negative charge, namely, when the body is completely emptied of the electric fluid; but two such bodies, both being negatively charged, should repel each other—and why?

There was much hesitancy on the part of the one-fluid advocates about pushing this argument to its logical conclusion. It remained for a bold German named Aepinus (1759) to seize the bull by the horns and assert that matter devoid of electricity is self-repellent.

This doctrine came as a shock to a generation many of whom could remember Newton. It was useless to point out that Newton had deduced the law of gravitation by observation of bodies that possessed their normal amount of electricity, and that the behavior of matter with the maximum negative charge was something which no one had ever observed. The one-fluid theory had received a serious jolt from which it never recovered; this argument was used against it as late as the 1830's. The attention of theoretical physicists of the eighteenth century was turned toward the two-fluid theory, and during the closing years of that century and the early part of the nineteenth the work of Coulomb, Laplace, Biot, and Poisson produced an elaborate and elegant mathematical theory which so well described all the electrostatic phenomena then known that by 1830 the two-fluid theory was generally accepted.

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[8] Newton, Principia, book 3: Rules of reasoning in philosophy.

But it often happens that as soon as one theory is comfortably settled on the throne another rises up to challenge its supremacy. We shall see the reign of each successive theory of electricity growing shorter. The thousands of years of the first era were followed by three centuries of the second. In the first half of the nineteenth century great things were happening. In 1820 Oersted had discovered that an electric current could produce a magnetic effect, thus tying together what had previously been regarded as separate phenomena. In 1822 Seebeck showed that electricity could be generated by heat. These discoveries impressed themselves on the mind of Faraday, then at work in the Royal Institution. He was familiar with the work of Davy in producing chemical decomposition by electricity, and the converse phenomenon of Volta, the production of electricity by chemical action. Faraday was also aware of the converse of Seebeck's discovery, the production of heat (and light) in the electric arc, and his thoughts turned naturally toward the undiscovered converse of the Oersted effect. He says himself at a later time [9] (1845):

> I have long held an opinion, almost amounting to conviction, in common, I believe, with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent, that they are convertible, as it were, into one another, and possess equivalents of power in their action. In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.

Such were the considerations which led Faraday to attempt the generation of electricity by means of a magnet (1831). The story is familiar to all of us; how he placed a magnet in a helix of wire and found that no current was produced except momentarily while the magnet was being placed in or taken out of the coil. This discovery seems to have made quite an impression in other than scientific circles, as is evidenced by some verse which has come down to us:

> Around the magnet, Faraday
> Is sure that Volta's lightnings play.
> To bring them out was his desire.
> He took a lesson from the heart;
> 'Tis when we meet, 'tis when we part,
> Breaks forth the hid electric fire.

Encouraged by this success, Faraday later (1845) sought and found a correlation between magnetism and light. Twenty years later this in its turn furnished the inspiration for Maxwell's electromagnetic theory, by means of which the domain of optics was annexed to that of electricity.

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[9] Faraday, Experimental Researches in Electricity, vol. 3, p. 1, London, 1855.

The publication of Maxwell's paper in 1865 may be considered as closing the second era of electrical theory, that in which electricity was regarded as a material fluid, and the opening of the third era in which the concept of electricity assumed a less material and more elusive form.

By 1865 the two great doctrines of nineteenth century physics, the conservation of energy and the correlation of physical forces (as foreshadowed by Faraday) had been enunciated and were well on the way to general acceptance. During the seventies and early eighties, electricity, in common with heat and light, was sometimes called, in the phrase of the day, a mode of motion, which meant a form of energy.

The adoption of this view was, of course, a matter of slow growth. Maxwell's electromagnetic theory had a long struggle for acceptance, so long, in fact, that Maxwell himself did not live to see its final triumph. He died in 1879, and it was not until 1886, when Hertz produced experimentally the electromagnetic waves which Maxwell's theory demanded, that its acceptance may be said to have become complete.

Against this concept of electricity as a mode of motion, that is to say, a form of energy, Lodge [10] in 1889 entered a protest. He pointed out that water or air under pressure or in motion represents energy, but that we do not, therefore, deny them to be forms of matter. He emphasized an important distinction between two terms: electrification, which is truly a form of energy, as it can be created and destroyed by an act of work, and electricity, of which none is ever created or destroyed, it being simply moved and strained like matter. No one, said Lodge, ever exhibited a trace of positive electricity without there being somewhere in its immediate neighborhood an equal quantity of the negative variety.

Lodge did much to crystallize the ideas of the time concerning the nature of electricity. These ideas, since Maxwell's merger of optics with electricity, had been, as Lodge pointed out, not clearly defined, but in general the idea was that electricity was in some way a phenomenon of the ether. Lodge enlarged upon this idea, explaining electrostatic phenomena as due to ether stress, electric currents as ether flow, and magnetism as ether vortices. Electricity, which had been previously regarded as a material fluid, now became an immaterial one, and in consequence this third period of electrical theory may be called the ethereal era.

As we mount toward the present time we see the different eras of electrical theory rapidly shortening in duration. While the spiritual

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[10] Lodge, Modern Views of Electricity, p. 7, Macmillan & Co., London, 1889.

era lasted several millenniums and the fluid theory three centuries, the ethereal era lasted only a few decades. The fourth era is that which is still with us. It may be called the atomic or quantum period, in which it is noteworthy that but little attention has been paid to the ultimate nature of electricity and a great deal to its structure. It is difficult to say when this period began, as, in fact, the ethereal era began to die almost as soon as it began to live.

Wilhelm Weber,[11] in 1871, in developing his theory of magnetism, pictured to himself light positive charges rotating about heavy negative ones, much like a satellite about a planet; and in 1874 Johnstone Stoney read before Section A of the British Association a paper entitled "The Physical Units of Nature", which was not printed until 7 years later.[12] In this paper he asserted the atomic nature of electricity and made a rough calculation of the elementary charge on the basis of Faraday's law of electrolysis. Ten years later[13] he was the first to use the term "electron."

Helmholtz,[14] in his Faraday lecture at the Royal Institution in 1881, further developed this line of thought, saying (p. 290):

> Now the most startling result of Faraday's law is perhaps this. If we accept the hypothesis that the elementary substances are composed of atoms, we cannot avoid concluding that electricity also, positive as well as negative, is divided into definite elementary portions, which behave like atoms of electricity.

Maxwell himself saw that his electromagnetic theory was essentially continuous in its nature, and recognized the difficulty arising from the implications of Faraday's experiments. In his "Treatise on Electricity and Magnetism" (vol. 1, p. 313, ch. 4, 1873), in the chapter on electrolysis he says:

> It is extremely improbable that when we come to understand the true nature of electrolysis we shall retain in any form the theory of molecular charges.

For Helmholtz, however, the atomic nature of electricity was beyond question. Electricity, as he saw it, was a special chemical element[15] whose atoms combine with those of other elements to form ions. Moreover, it appeared to be a monovalent element, for it seemed that a monovalent element combined with one electron, a bivalent one with two, and so on, exactly as a chlorine atom combines with one atom of hydrogen and an oxygen atom with two atoms of hydrogen. Helium, with its zero valence and double electrical charge, was as yet unknown.

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[11] Millikan, The Electron (2d ed.), p. 20, University of Chicago Press, 1924.

[12] Stoney, Phil. Mag., vol. 11, pp. 381–390, 1881.

[13] Stoney, Sci. Trans. Roy. Dublin Soc., 11th ser., vol. 4, p. 563, 1891.

[14] Helmholtz, Journ. Chem. Soc. (London), vol. 39, pp. 277–304, 1881.

[15] Graetz, Recent Developments in Atomic Theory, Methuen & Co., London, 1923.

The inevitable process of reconciliation of these contradictory theories was early begun by Lorentz,[16] who suggested for this purpose his electron theory of electricity. On this theory all the effects of electricity inside bodies were explained on the assumption of electrons, and all the effects of electricity at a distance, electrostatic, electromagnetic, and inductive, required the help of the ether. To unite these two classes of phenomena he assumed that each electron was closely bound up with the ether, and that any change in configuration of the electrons produced a change in the ether which was propagated with the velocity of light, and thus produced action at a distance.

About this time an entirely new line of experimental research was developing which was destined eventually to make the atomic concept of electricity dominant for a time. This was the study of the electric discharge in high vacua. Several workers had investigated this field without attracting much notice, but it remained for Crookes to direct widespread attention to this class of phenomena by an exhibition of novel and beautiful effects in vacuum tubes which he gave at the meeting of the British Association at Sheffield in 1879. Crookes unquestioningly assumed these effects to be due to electrified molecules of residual gas in the tube. It was shown later by others (J. J. Thomson, Townsend, Wilson, Millikan) that the negatively charged particles in a Crookes tube were not molecules or even atoms, but bodies of a minuteness previously unknown, about the 1/1800th part of a hydrogen atom in mass, and bearing a definite negative charge of electricity. For these tiny bodies the term electron, introduced by Stoney, was revived. Still later work brought to light the proton, with an equivalent positive charge but larger mass than the electron and, in our own day, the positive electron.

As a result of this new line of investigation it became clear that a great many electrical phenomena required the atomic theory of electricity for their explanation. A great many, but not all; for a large number refused to fall in line under a corpuscular explanation, but could be simply and completely explained on Maxwell's theory as ether disturbances. The discovery by Hertz of the electromagnetic waves predicted by Maxwell did much to swing the pendulum back in this direction. The reconciliation of these contending views has been carried on much along the line originally taken by Lorentz. It is of interest to note that his idea of an electron inseparably bound up with the ether is found today in all essentials in the theory of wave mechanics.

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[16] Lorentz, Verslagen en Mededeelingen der Koninklijke Akademie van Wetenschappen, Amsterdam, vol. 8, pp. 323–327, 1891. Also Arch. Neérlandaises, vol. 25, p. 432, ch. 4, 1892.

We have now brought this somewhat hurried survey of electrical history up to the present day. We have seen that past speculations as to the nature of electricity fall into four classes, each corresponding to an era of thought. In the first of these eras, beginning probably with the earliest observations of electrical attraction, and terminating in the middle of the sixteenth century, electricity was regarded as a soul or spirit. The second era may be said to have been opened by Cardan in 1551 and closed by Maxwell in 1865. During these three centuries electricity was regarded as a material fluid of one or two kinds. It is worthy of note that during this period the concept of the electrical fluid showed a trend toward the immaterial, from Cardan's "fatty and glutinous humor" to the impalpable and imponderable fluid of the early nineteenth century. In the third era electricity in its various manifestations was regarded as some kind of an ether disturbance of a continuous nature. The fourth concept emphasized the atomic or discontinuous structure of electricity without any suggestion as to the ultimate nature of these atoms.

But though speculation as to the ultimate nature of electricity has been in abeyance since the opening of the twentieth century, it will certainly arise again, and, within limits, it is well that it should. We may, therefore, turn now to an examination of the wealth of material which the last 40 years have placed at our disposal and see what it may contain that is likely to be of importance in guiding and suggesting future speculation as to the nature of electricity.

The emphasis laid by the twentieth century on the structure, rather than the nature, of electricity is natural, for structure is much more easily determined than nature, and, moreover, a knowledge of the first is likely to give us some useful hints as to the second. It appears that the discontinuous structure of electricity goes almost hand in hand with that of matter. A tabular view of the known elementary particles of matter with their associated charges of electricity will be useful.

Charge	+	−	0
Mass: Heavy	Proton	. . .	Neutron
Mass: Light	+Electron	−Electron	(Neutrino)

The heavy particles now known, the proton and the neutron, have a mass equal to that of a hydrogen atom; the light particles have about 1/1800 of this mass. The light neutral particle has not yet been discovered, but so urgent is the demand for it in current nuclear theory that it has been named before its advent.

According to the idea that has prevailed for 2 centuries, positive and negative electricity should be merely reflected images of each other, their properties being equal and opposite. The behavior of the negative electron and the proton shows nothing inconsistent with this concept as far as electrical properties go. On the discovery of the positive electron it was at first thought that it was shorter lived, or, as a chemist might say, more reactive than its negative counterpart, but this has not been borne out by subsequent investigation.[17] The mass associated with the positive charge in this case has been investigated by several persons. The latest work is that of E. Rupp[18], who finds that the mass is within 5 percent of that of the negative electron. Rupp appears to have found one point of difference between the two which, if confirmed, will be of importance.

It has been found that the passage of negative electrons through thin films of metal is accompanied by a diffraction effect, photographs of the electron beam after transmission showing a series of concentric rings. Rupp passed negative and positive electrons through the same films of gold and aluminum, and found that while the negative particles gave the usual rings the positive particles showed a continuous scattering. We will return to the interpretation of this later.

As to the neutron, it is still uncertain whether it is a proton which has acquired a negative electron or whether it is to be regarded as an independent entity without electric charge. The latter, as we shall see later, would be in serious conflict with present accepted electrical theory.

There was a time, not so very long ago, when the atom of matter was considered to be its ultimate structural unit. The discovery of the proton and the electron gave meaning to the term subatomic. With this in mind, the question naturally arises as to a possible further subdivision of the electron. Several observers have claimed to have found evidence of smaller charges than that carried by the electron, but Millikan,[19] after an exhaustive discussion of the subject, came to the conclusion that up to 1924 there had been adduced no satisfactory evidence of this smaller charge.

In the early years of the present century there was some discussion as to whether the electron was to be regarded in shape as a rigid sphere (Abraham) or as contractile. The latter hypothesis was advanced by Lorentz to explain the negative result of the Michelson-Morley experiment. Lorentz supposed the electron, by

[17] Allowing for relative abundance.

[18] Rupp, Phys. Zeit., vol. 35, p. 999, 1934. But in Zeit. Phys., vol. 93, p. 278, 1935, Rupp has withdrawn his earlier article for further verification.

[19] The Electron, chap. 8.

motion through the ether, to flatten into an oblate spheroid. Experiments by Bucherer [20] in 1909 were interpreted as favoring the hypothesis of Lorentz.

But in 1927 a new line of experimental evidence as to the structure of the electron was opened up by Davisson and Germer,[21] soon followed by G. P. Thomson.[22] These investigators found in brief, that electrons (of the negative variety) might be scattered by reflection or diffracted by passage through very thin films of metal in such a way as to suggest that an electron is at least as much like a little bunch of waves as it is like a particle, and that neither aspect can be ignored.

This is well brought out by G. P. Thomson's diffraction rings. The electron must have a wave aspect, or there would be no interference pattern; it must have a charged particle aspect, or the whole ring system would not be deflected by a magnet, as it is found to be. The whole situation, in fact, had been foreshadowed theoretically by the wave mechanics of de Broglie and Schrödinger.

A number of explanations have been offered for this dual behavior. Perhaps the most completely worked out is that of J. J. Thomson,[23] based upon the diffraction rings obtained by his son, which lend themselves particularly well to theoretical treatment. On this view the electron is associated with and accompanied by a group of waves which guide and direct its motion. Now it was found by a study of the speed of the electrons and the associated wave lengths in the diffraction rings that a curious and complicated relation existed between these quantities. If u is the velocity of an electron and λ its associated wave length, this relation is:

$$\frac{u\lambda}{\sqrt{1-u^2/c^2}}=C$$

in which c is the velocity of light and C is a constant.

But this, as J. J. Thomson shows, is exactly the relation that should hold for the group speed of electromagnetic waves in a medium such as the Kennelly-Heaviside layer, containing a multitude of electric charges, positive and negative.

J. J. Thomson therefore suggests the following structure for the negative electron:

I. A nucleus which, like the older concept of the electron, is a charge of negative electricity concentrated in a small sphere.

II. This nucleus does not constitute the whole of the electron. Surrounding it there is a structure of much larger dimensions which

[20] Bucherer, Ann. Phys., vol. 28, p. 513; vol. 29, p. 1063, 1909.
[21] Davisson and Germer, Phys. Rev., vol. 30, p. 705, 1927.
[22] Thomson, G. P., Proc. Roy. Soc., vol. 117, p. 600, 1928.
[23] Thomson, J. J., Beyond the Electron, Cambridge Univ. Press, 1928; Phil. Mag., vol. 6, p. 1254, 1928.

may be called the sphere of the electron. This sphere contains an equal number of positive and negative charges, forming a little Kennelly-Heaviside layer around the nucleus. Measurements on the diffraction rings indicate a diameter for this sphere at least 10,000 times that previously accepted as the diameter of the electron.

III. The nucleus is the center of a group of waves and moves with the group speed in its atmosphere of electric charges.

At the time that J. J. Thomson proposed this hypothesis the positive electron was not known. Here comes in the importance of Rupp's work previously referred to. On their face these experiments indicate either that the train of waves that accompanies a negative electron is absent from the positive electron, or that all possible wave lengths are present.

Just as the atom, once regarded as an ultimate structural unit, is now recognized as a complex of electrons, protons, neutrons and possibly neutrinos, so the electron, it seems, must be regarded as a similar complex. Much more, doubtless, is to be learned about its structure before we can hope to answer the question, What is electricity?

Perhaps the most outstanding fact in modern physical theory is the dominant position occupied by electricity. In the nineteenth century one spoke of matter and electricity as two separate and independent entities; nowadays electricity has become the fundamental entity of which matter is merely an aspect. Matter, once supreme, has lost its individuality and has become merely an electrical phenomenon which electricity may exhibit more or less according to circumstances.

It is obvious that our answer to the question: What is electricity? will be fundamentally influenced according to whether we hold an electrical theory of matter or a material theory of electricity. It will therefore be worth our while to examine the foundation for the present view that electricity, whatever it may be, is the sole world-stuff. So radical has been this change in our thinking that it would seem a foregone conclusion that it must be based upon the clearest and most unequivocal of experimental evidence.

This change in our concepts did not come suddenly. Its beginning dates back to 1893, when J. J. Thomson [24] showed on theoretical grounds that a charged sphere in motion through the ether would encounter a resistance which to all intents and purposes would appear as an increase in the sphere's inertia, i. e., in its mass. Calculation indicated that this effect would become appreciable only if the velocity of the charged body was comparable to that of light.

[24] Thomson, J. J., Recent Researches in Electricity and Magnetism, p. 21. Clarendon Press, Oxford, 1893.

In 1893 this suggestion was of academic interest only, no bodies moving with sufficient speed being then available for experiment. A few years later conditions had changed. The study of radioactive substances and of the discharge of electricity through gases had placed at our disposal positively and negatively charged particles moving with unprecedented speeds, which in the case of the negative particles were in some cases comparable with the speed of light. Here, it would seem, was an opportunity to test Thomson's theory of increasing mass.

Unfortunately, the conditions of the problem were such that it was not at first possible to obtain a measure of the mass of such a particle, but only a determination of the ratio of the electric charge to the mass which carried it (e/m).

Kaufmann [25] found, however, that for the swifter particles this ratio was less than for the slower ones. There were only two ways of explaining this fact, both equally radical: either the mass increased or the charge diminished as the speed of the particle became greater.

In this dilemma opinion inclined generally to the first alternative, largely because there was in existence a theoretical reason to expect it, while no one as yet had been ingenious enough to suggest any reason why a moving charge should alter. It is of importance to note that Kaufmann's experimental result, because of its equivocal character, cannot be accepted as more than half proving J. J. Thomson's theory.

Kaufmann calculated that such particles as he experimented with might have, when moving slowly, an electrical mass equal to about one-fourth their total mass. In making this calculation he assumed that a particle behaved as though it were a little metallic conductor, but he was careful to point out that a different assumption might lead to another result.

J. J. Thomson, on the assumption that a particle had no metallic conductivity, but acted like a point charge, found that Kaufmann's results indicated that the whole of the mass of the particle might be accounted for electrically.

This was the origin of the electrical theory of matter. Its pedigree goes back to J. J. Thomson's theory, which in turn was derived from the electromagnetic theory of Maxwell. Kaufmann's experiments only half proved Thomson's theory, which in addition was complicated by a special assumption with regard to the distribution of the charge on the particle. Without this assumption only a part of the mass could be accounted for electrically.

[25] Kaufmann, Gesell. Wiss. Göttingen, Nov. 8, 1901; July 26, 1902; Mar. 7, 1903.

But much water has run under the bridge since 1893. Forty years is a long life for any physical theory in these days, and the recent discovery of the neutron has brought with it a challenge to the electrical theory of matter.

In J. J. Thomson's original theory of the increase in mass of a moving charge it was an essential point that the lines of force should be free to adjust themselves as the motion demanded. As a leaf or a card tends to flutter down through the air broadside on, so the lines of force, originally distributed radially and symmetrically about the charge at rest, will tend to set themselves in a plane perpendicular to the direction of motion of the charge. They will not all be able to lie in this plane because of their mutual repulsion, but the density of the lines will be a maximum in this plane and a minimum in the direction of motion, and a certain space distribution will result of such a nature that the apparent increase of mass can be completely accounted for.

But it is essential for this result that the lines of force shall be perfectly free at their outer ends; in other words, only a single isolated charge is considered. Now, in a structure like the hydrogen atom, composed of a negative and a positive particle, there is bound to be some interference with this freedom of adjustment. In a neutral, nonionized atom it would appear that all of the lines must begin and end within the atomic structure.

J. J. Thomson must be given credit for foreseeing this difficulty, though the Bohr atom was as yet years in the future. He had an atomic concept of his own in mind at that early date and pointed out that the distance between the particles constituting an atom must be thousands of times the diameter of a particle. In consequence, he said, almost all of the mass will originate where the lines have their greatest density, near each particle; and the particles are relatively so far from each other that the parts of the lines of force in their immediate neighborhood will have almost perfect freedom of orientation with the motion of the atom.[26]

This is a quantitative question; but it is clear that only under the most favorable conditions will we have a freedom of motion in the atom which approximates that around an isolated charge, and in consequence the electrical explanation of matter on J. J. Thomson's theory must be in the same degree approximate.

With the neutron, conditions are more rigid. Assuming the neutron to consist of a proton and a negative electron, the union of these must be almost as close as possible, as the neutron, on modern theory, may form a constituent of an atomic nucleus. Here we are dealing not with atomic magnitudes but with subatomic dimensions, which is

[26] Thomson, J. J., Electricity and Matter, p. 51, Scribner's, New York, 1904.

quite another thing. Freedom of motion of the lines of force in such a structure must be almost nonexistent. And if we make the alternative assumption that the neutron is an independent, nonelectrical entity, the electrical theory of matter must admit of an important exception.

But an electrical theory of matter to be acceptable must admit of no exceptions. It must obey the "all or none principle." If it is approximate in even the slightest degree we are confronted with the existence of two kinds of matter, ordinary and electrical, and we are violating the rule of simplicity in reasoning laid down by Newton.

But has there not been later evidence supporting this theory?

It has sometimes been said that Millikan's oil-drop experiments, by which he measured the charge on a single electron, prove the constancy of this charge, and hence the variability of the mass alone in Kaufmann's experiments. It is true that Millikan found that the charge on an ion after it had been transferred to the oil drop was the same whatever the source of the original charge. Ions of different gases, unquestionably of different speeds, gave the same charge to the drop. But it is to be remembered that the measurement of this charge was made not at the speed of the ion but at that of the oil drop, which was of the order of a few hundredths of a centimeter per second.

The special theory of relativity is sometimes quoted in support of the constant charge and variable mass. It is true that Einstein [27] in his original paper of 1905 gives a formula for the change of mass with the speed of a moving electron, which, like J. J. Thomson's formula, becomes infinite at the speed of light, and that he gives no similar formula for a change in the charge. It will be interesting for us to see how he obtained this result.

In section 10 of his paper Einstein derives the following formula for the x-component of the acceleration of a moving charged particle, together with formulas for the other components:

$$\frac{d^2x}{dt^2}=\frac{e}{m}\frac{1}{\beta^3}X$$

in which e is the charge on the particle, m its rest mass, X the component of the electric vector, and β the familiar $1/\sqrt{1-v^2/c^2}$.

It is evident that the quantity e/m is altered by the factor $1/\beta^3$, but whether the charge or the mass or both are changed is not obvious. Einstein without comment assumes e to be constant and m to bear the full effect of the modifying factor, and on this basis derives his formula for the change of mass.

[27] Einstein, Ann. Phys., vol. 17, p. 891, 1905.

This assumption, of course, was orthodox in 1905, but it is of interest to note that as a matter of logic the electrical theory of matter can claim no supporting evidence from the special theory of relativity.

On the basis of this result of Einstein, Sommerfeld [28] introduced a modification into Bohr's theory of the atom. On Bohr's theory the hydrogen atom was regarded as consisting of a negative electron revolving in a Keplerian ellipse around a positively charged nucleus, the attraction between the two charges being balanced by the centrifugal force of the revolving electron. Sommerfeld (p. 45) makes the orthodox assumption that the electrical charges remain constant, but that the mass of the revolving electron varies with its speed according to Einstein's formula. In consequence the mass of the electron fluctuates as it describes its orbit, being greatest at perihelion and least at aphelion, and its centrifugal force will vary slightly from that in a nonrelativistic Keplerian ellipse. Because of this the orbit becomes an ellipse with a moving perihelion, like that of the planet Mercury. The effect of this will be to split up the spectral lines, producing what Sommerfeld called the relativistic fine structure.

This predicted effect has actually been found in the spectra of hydrogen and helium, the number of the component lines and their relative separation being in accordance with theory.

As to the value of this result as a confirmation of the electrical theory of matter, it is to be observed that Sommerfeld would have obtained exactly the same modification of the Keplerian ellipse if he had assumed the charge to decrease and the mass to remain constant, thereby disturbing the balance by reducing the centripetal attraction instead of increasing the centrifugal force.

The logic of the whole situation is that the electrical theory of matter can claim no independent support from Millikan, Einstein, or Sommerfeld. It rests for the present on J. J. Thomson's theory, and even this theory assumes tacitly that the charge is unaltered by the motion. It is remarkable that everyone we have mentioned, from J. J. Thomson onward, when confronted with the necessity of making a choice, prefers to keep the charge constant and let the mass take the consequences, and this without comment or apology.

Of course, there must be a reason for this; and although it is explicitly stated by no writer that I have seen, the reason is doubtless to be found in a fundamental law of electricity, that of the conservation of electrical charge, with its corollary, the exact equivalent of positive and negative electricity. This law states that no one has ever produced the slightest trace of a positive charge without the simultaneous production of an equal and opposite negative charge somewhere in the neighborhood.

[28] Sommerfeld, Ann. Phys., vol. 51, p. 1, 1916.

This law has been the subject of some very searching experiments. We may operate within a large conducting cube, such as was built by Faraday at the Royal Institution; perform within it all the usual electrical experiments; excite a glass tube by rubbing it with fur; draw sparks from an electrical machine; and yet a sensitive gold-leaf electroscope connected to the cube will remain undisturbed. It seems impossible to create or destroy an electric charge without a compensating creation or destruction of an equivalent charge of the opposite sign.

And yet the era of thought which has not hesitated to question the conservation of energy can hardly be expected to respect this electrical principle; and, in fact, this law has been brought under fire from several quarters. If these points of order are sustained, they will have an important bearing on future answers to the question, What is electricity?

It is well to remember in this connection that all the experiments upon which is based the law of conservation of electric charge have started with neutral bodies. The glass tube and the fur were at first neutral, but exhibited equal and opposite charges after being rubbed together; the electrical machine was at first neutral, but on being operated its two sides became equally and oppositely charged.

Suppose a chemist should announce that as a result of the analysis of several thousand neutral salts he had come to the conclusion that acid and basic radicals existed in equal amounts in nature; we would likely think him ignorant of such syntheses as that of the acid radical cyanogen (CN) from its elements in the electric arc. But is there any known electric analogue of such a synthesis or its reverse dissociation? No; nothing that we have so far been able to produce in the laboratory; yet if we imagine some race of children of the gods who could play with planets as we with pith balls, something of this kind might come to their notice.

Among the phenomena of atmospheric electricity there is an unsolved mystery. Many fruitless attempts have been made to explain it consistently with the principle of conservation of electrical charge. Continual failure has led more than one physicist to look for the explanation in a slight departure from this principle, and it has been shown that a departure so slight as to be beyond laboratory detection would yet, on the large scale, solve this mystery. The difficulty in question is to account for the negative charge of the earth.

Our earth is not a neutral body. Its entire surface is negatively charged to such an amount that there exists near the surface a potential gradient of 150 volts per meter. The conductivity of the atmosphere is small, but not zero; and because of this conductivity and the potential gradient there is a continual conduction of negative

electricity away from the earth amounting, over the whole surface of the earth, to a current of about 1,000 amperes. Small as this may appear, it is sufficient to bring about a loss of 90 percent of the earth's charge in 10 minutes if there were no means of replenishing the loss. The nature of this replenishment is the mystery referred to.

So great has been the difficulty of accounting for this replenishment that in 1916 G. C. Simpson,[29] now director of the British Meteorological Office, raised the question of a possible spontaneous production of a negative charge in the earth's interior, but offered no suggestion as to how this could be brought into line with existing theory.

In 1926 Swann,[30] who had worked unsuccessfully with the same problem, followed Simpson's lead, but chose the other alternative of a slight annihilation, or as he called it, "death of positive electricty." He was able to bring this into connection with existing electrical theory by generalizing Maxwell's equations. His fundamental idea was that there might be a very slight difference in the properties and behavior of the two electricities. Here again we are reminded of the difference apparently found by Rupp.

Such a suggestion was not without precedent. Lorentz [31] in 1900 had postulated a difference between the attraction of unlike charges and the repulsion of like charges to account for another mystery—gravitation. It must be admitted that the accepted idea of the absolute equivalence and mirror-image character of the two electricities had weakened somewhat when such men as the director of the British Meteorological Office, the director of the Bartol Research Foundation and a Nobel prizeman could join in expressing doubt of its accuracy.[32]

Swann's theory of the maintenance of the earth's charge is, from the theoretical point of view, the most successful that has yet been advanced. He modifies the equations of Maxwell by introducing two small terms, amounting respectively to one part in 10^{26} and five parts in 10^{19} of the main term of the classical theory. These additional terms involve the acceleration and time rate of change of positive charge.

Swann assumed no similar terms for the negative charge, his idea being that there is a slight differential effect in behavior. For simplicity, therefore, he introduced a differential term applying only to positive electricty. This assumption enabled him to account for

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[29] Simpson, G. C., Monthly Weather Rev., vol. 44, p. 121, 1916.

[30] Swann, Journ. Franklin Inst., vol. 201, p. 143, 1926. Phil. Mag., vol. 3, p. 1088, 1927.

[31] Lorentz, Koninkl. Akad. Wetensch. Amsterdam, Proc. Sec. Sci., vol. 2, p. 559, 1900.

[32] Additional references: More, Phil. Mag., vol. 21, p. 196, 1911. Gleich, Ann. Phys., vol. 83, p. 247, 1927. Anderson, W., Ibid., vol. 85, p. 404, 1928. Press, A., Phil. Mag., vol. 14, p. 758, 1932.

a slow death of positive electricity due to the centripetal acceleration produced by the earth's rotation.

To account for the known electrical facts, there is necessary an annihilation of less than one proton per cc per day, equivalent to a loss of 0.5 percent of the earth's mass in 10^{20} years. This would also account for as much of the earth's magnetic field as is symmetrical about the earth's axis, and would give the correct ratio for the magnetic fields of the earth and the sun. Moreover, no development of charge or magnetic field could be detected with a sphere of laboratory size rotating at the highest practicable speed. And finally, Swann's scheme is consistent with the special theory of relativity.

Whatever may be thought of Swann's fundamental assumption, it must be admitted that his theory is experiment-proof. Moreover, even though it should be definitely disproved, it would have the lasting merit of impressing upon us caution in extrapolating laboratory results to the cosmic scale.

The relations of newly discovered fact and existing theory are, as we have seen in this somewhat brief survey, rich in suggestion. Speculation is not dead but sleeping. If the past is still an indication of the future, it will awake again to renewed activity, and when this occurs we will need a wide acquaintance with fact and a good sense of perspective to guide and direct future speculation on the question: What is electricity?

NEW FACTS ABOUT THE NUCLEUS OF THE ATOM[1]

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[With 2 plates]

No depression has existed during the past 5 years in the world of scientific activity. During this period important advances in the field of "nuclear physics" have come with startling rapidity. Each one of these steps forward has opened up fresh fields for exploration, and successful attempts—made in feverish haste—are daily uncovering new facts and relationships. The frequency with which announcements of new discoveries are appearing almost makes any contemporary survey out of date before it can reach the reader's eye.

Nuclear physics is a subdivision of the general field of atomic physics. The scientific activities begun before the opening of the present century and continuing up to the present day have given to us a satisfactory and rather complete picture of the atom as a whole. We now know it to be a small complex unit about one one-hundredth of a millionth of an inch in size, containing at its center an exceedingly small core or nucleus surrounded by one or more electrons, the number of electrons determining the classification of the atom as a particular element. The electrons which surrounded the nucleus are known as "extranuclear electrons." Research of the past two or three decades has, for example, counted the extranuclear electrons which surround the nucleus in each one of the chemical elements. We know that hydrogen has 1 such electron, helium 2, and so on up to uranium, which has 92. Both the mass and electric charge of the electron have been accurately measured, and the masses of the nuclei of most of the elements have been determined.

Furthermore, through the cooperation of the mathematical physicists and the experimenters in the laboratory, the motions and most of the general properties of these extranuclear electrons can today, in a scientific sense, be said to be understood.

[1] Reprinted by permission from the General Electric Review, vol. 37, no. 12, December 1934.

Not so, however, with the nucleus itself. Despite the new facts brought to light in the last fertile 5 years the nucleus still remains a bundle of mysteries and even contradictions. Rather than simplifying the situation the newer discoveries have shown the nucleus to possess a more varied and complicated personality than previously could have been permitted in the dreams of even the most imaginative

Before attempting a consideration of the recent discoveries, let us recall the picture which in the mind of the physicist represented the 1929 model of the nucleus. It was an agglomerate of electrons and protons fastened together into a very small and very tightly bound structure. The electron, now so familiar to everyone, is a unit of negative electricity. No matter what its origin, it is always found to possess the same definite charge of negative electricity and the same mass. It is one of the building stones of all matter. It is a fundamental particle. The proton was considered the second and only other fundamental particle. It possesses an electric charge equal in magnitude to that of the electron, but opposite in sign and therefore positive; and has a mass nearly 2,000 times as great as that of the electron. Hydrogen, the simplest of all atoms, has for its nucleus a single proton; and therefore contains a single extranuclear electron to balance the charge of the proton and render the net charge of the atom equal to zero. After the experiments in 1919 by the present Lord Rutherford, in which he succeeded in observing protons driven out of the nuclei of nitrogen by bombardment with alpha particles—which are nuclei of helium atoms spontaneously emitted from radioactive substances—and, after it was shown that protons could be obtained in a similar manner from various other elements as well, it was generally assumed that all nuclei were built up of protons and electrons. On the basis of such a concept of the structure of nuclei, it was possible, if one were not too critical, to explain many of the known properties of nuclei.

Each nucleus was assumed to contain a number of protons equal to its atomic weight. But, to affix a correct value to the electric charge of the nucleus, it was necessary to assume also that in all nuclei, with the exception of hydrogen, were imprisoned a number of electrons which canceled part of the positive charge of the protons. The latter assumption, however, presented a grave difficulty. The same theories which so successfully explained the behavior of the extranuclear electrons would not permit any nucleus to contain so much even as one electron. It was impossible to see how a particle of the mass of an electron could be confined to a region of space as minute as a nucleus. This difficulty cannot be resolved on the basis of present theories. They were developed to describe the properties of an atom in which

the regions of space involved are of the order of, say, one-billionth of an inch; and become meaningless when applied to phenomena confined to regions of space a thousand times smaller in extent, such as those required for a nucleus. This difficulty will be resolved only by the extension or revision of the present theory and by the development of new fundamental theoretical concepts.

But, as we stated, the 1929 model of the nucleus, when uncritically judged, had many successes. It could account, for instance, for the charge and mass of all nuclei. The existence of isotopes (nuclei of the same charge but different mass) and of isobars (nuclei of the same mass but different charge) could be explained simply by choosing the proper numbers of protons and electrons out of which to build the nucleus.

The three well-known types of rays emitted by radioactive substances seemed also to have a place in this picture. Gamma rays, a form of radiant energy consisting of streams of high-energy photons, were attributed to the release of potential energy stored in the nucleus. Alpha rays, helium nuclei consisting each of 4 protons and 2 electrons, represented an alternative mode of release of potential energy in which the 4 protons and 2 electrons removed from the nucleus were bundled together in a stable unit which carried off the energy. Beta rays, comprising a third form of the release of energy, consisted simply of streams of fast-moving electrons.

In a word, then, all the positive electricity in the world was locked up in the form of protons, and appeared only in nuclei. All the negative electricity existed as electrons, some of which were locked in nuclei while the remainder encircled the nuclei as extranuclear electrons. The proton and the electron constituted the two fundamental building stones out of which all matter was to be constructed.

THE NEUTRON

Destiny, however, had arranged for a sudden change of this whole point of view. The first inkling of the new knowledge came in 1930; though the full import of its significance was not realized until nearly 2 years later. W. Bothe and H. Becker in Germany, in 1930, allowed alpha particles to strike, not nitrogen as Rutherford had done, but instead the very light metal beryllium. With their apparatus they did not observe the emission of protons, but instead a very penetrating ray capable of passing through several inches of lead, even more lead than the most penetrating gamma rays which arise in the natural radioactive substances. From its great penetrating power they concluded that their new ray must be a very powerful gamma ray. This, as we shall see later, was not entirely correct.

The scene now shifts to France, and we find F. Joliot and his wife, Irene Curie, the daughter of the late Madame Curie, studying further the new Bothe-Becker rays. They brought to light the very important fact that when these rays pass through matter they impart energy to nuclei and set them in rapid motion. These rays are then unlike ordinary gamma rays, which are known to impart energy almost wholly to electrons only. But still the rays kept their secret; and again the scene shifts, this time to England.

J. Chadwick, profiting by the German and French experiments, turned his attention to these mysterious rays. He measured the distance that various kinds of nuclei set into motion by the rays were able to penetrate through matter. In a short time he realized that the gamma-ray interpretation was entirely inadequate; but that all the effects could be coherently explained by assuming that the rays consist of a stream of particles about as massive as protons, although unlike protons, and unlike any material particles ever before observed, they are neutral electrically. Despite the initial skepticism on the part of many scientists, in a few weeks' time, after further work by Chadwick and by others, this very revolutionary interpretation of the experiment was universally accepted and the existence of the neutron was established. The neutron was almost, but not entirely, a new concept, for in 1920 both Harkins and Rutherford had suggested the possible existence of such a particle, although not until 1932 were the experiments performed and the proof obtained. That date, therefore, remains as the neutron's birthday.

The discovery of the neutron was not by any means unwelcome, for it was immediately recognized that instead of electrons and protons one might use neutrons and protons out of which to build nuclei, thus avoiding the difficulty previously mentioned of confining electrons within nuclear dimensions. In fact, Heisenberg announced a preliminary theory of nuclear structure based on such a model.

Chadwick suggested that the neutron itself may represent a very close combination of electron and proton; though it is not impossible that it may be itself a new fundamental particle.

THE POSITRON

During the time that the European physicists were busying themselves with the experiments which led to the discovery of the neutron, in California there was in progress another type of experiment which resulted in the discovery of the positive electron or positron, as this particle is now generally designated.

The subject of study in this instance was the cosmic radiation. In the spring of 1930 Professor Millikan and the writer, in collaboration, planned an apparatus designed to measure directly the speeds

and energies of the individual particles which were known to be ejected from all material substance through which these rays passed. A modified form of the well-known Wilson cloud chamber was incorporated into a powerful electromagnet. By means of the cloud chamber it was possible to photograph not an individual electron itself but an outline of the exact path followed by the electron in its passage through the gas of the chamber. We might compare this process to that of an observer in an airplane flying very high, who, though unable to discern a ship, might see very clearly its wake in the water. Through the aid of the magnetic field the speeds or energies of the individual electrons can be determined. Any electrically charged particle, such as an electron, when between the pole pieces of a magnet, moves not in a straight line but in a curved path. A measurement of the radius of curvature then allows the speed to be easily calculated.

This experiment showed at once several striking results. Electrons of prodigiously high speeds were observed, some of them having more than 99 percent the velocity of light; but of far more importance than this was the fact that many of the particles, from the sense in which they curved in the magnetic field, were seen to contain a positive electrical charge. This observation showed immediately that the nucleus of the atom plays an important role in the absorption of the cosmic rays. It was an observation of a nuclear process, entirely different but in a sense analogous to that made by Rutherford in 1919, when he observed protons driven out of nitrogen nuclei.

The results of these preliminary observations were reported in the fall of 1931, and the spring and summer months were spent in studying the properties of these particles of positive charge. A plate of lead was inserted into the cloud chamber to act as a barrier for the particles. A particle in passing through this lead plate would give up a part of its energy and emerge from the plate with a lower velocity than it possessed upon entering; hence the sharpness of the curvature in the magnetic field of the particle before and after traversing the plate would show a difference, depending upon the amount of energy lost in the plate. Measurements made on the track of a particle before and after passing through a plate, together with observations of the density of the track itself, give definite information about the mass of the particle and the magnitude of the electric charge it carries.

In August 1932 a photograph was obtained which showed clearly a particle of positive charge passing through the plate of lead and emerging with a lower energy. The evidence presented by this photograph was so clear-cut that after the negative film was removed from the developing bath and before it was dry, we reached the conclusion that this particle might represent a positive electron.

Later study and careful measurement only tended to strengthen the interpretation that a fundamental particle of a new kind was present among the cosmic-ray particles. After several more photographs showing evidence of a similar kind were obtained, the discovery was announced early in September 1932.

In March 1933 P. M. S. Blackett and G. P. S. Occhialini in Cambridge, England, confirmed our announcement of the existence of the positive electron or positron. They used an apparatus of a similar kind, though with the added advantage that a cosmic-ray particle in passing through their apparatus would itself actuate the mechanism and cause a photograph of its path to be taken.

During the following weeks workers in California and in various European laboratories carried out lengthy investigations on positrons. It was found that it was not necessary to rely upon cosmic rays, but that rays of laboratory origin could produce them as well. First, Chadwick, Blackett, and Occhialini showed that positrons were produced by the radiations generated when alpha particles from a radioactive substance were allowed to strike beryllium. The radiations in this case are complex in character, consisting both of neutrons and gamma rays; but in their experiment it was not possible to determine which of the rays was responsible for the production of the positrons. Curie and Joliot by a similar experiment, in which they inserted blocks of lead and paraffin into the path of the rays producing the positrons, showed that the positrons arose more likely as a result of the gamma rays than of the neutrons.

The first direct proof that the well-known gamma rays from thorium can give rise to positrons was given by S. H. Neddermeyer and the writer. If the gamma rays are allowed to pass through a rather thick piece of lead and if the ejected electrons are observed, most of them are found to be of negative sign although some 10 percent are positive. Besides determining the relative numbers of positive and negative electrons, these experiments determined also the speeds or energies with which the electrons of both signs were ejected.

Here an observation was made which is of importance in deciding just how the positrons are produced. The most energetic positrons were found to have less energy than the most energetic negative electrons by a definite amount corresponding approximately to 1,000,000 electron-volts.[2]

To point out the significance of the energy difference of 1,000,000 electron-volts, we must go back a few years and consider what the mathematical physicists had been thinking and doing while the other class of physicists, the experimenters, were performing their tests.

[2] The electron volt is a convenient unit for the measurement of electron energies and is equivalent to 1.6×10^{-12} ergs or 1.2×10^{-19} foot-pounds.

One of the chief mathematical problems of the day was to incorporate the theory of relativity into quantum mechanics. In this connection the endeavors of P. A. M. Dirac resulted in considerable success when he wrote down his famous equation, now known as the "Dirac electron-equation."

This equation proved remarkably successful in solving a variety of problems which had hitherto baffled the theorists; but it contained one very striking feature which was a source of considerable annoyance. It required that electrons should under certain conditions have a negative energy and negative mass; they should have less than zero energy and weigh less than nothing. Dirac considered each point in space, including empty space or a perfect vacuum, to be "filled" with an infinity of such negative energy electrons. He also made the assumption that these negative mass electrons were unobservable and that it was a property of free space that they should be there. Dirac stated in 1930 that if one of these electrons should be removed, the "hole" in space that remained would manifest itself as an electron of positive electrical charge and of positive mass and energy.

The logic is perfect, for taking away less than nothing from space is equivalent to putting something there.

Because no positive electrons had ever been observed and because of a natural repugnance toward the idea that an infinity of electrons of negative mass should occupy each point in space, practically all theoretical physicists considered this feature of Dirac's equation an unfortunate weakness. Because of the success of his equation, however, they continued to use it.

But the discovery of the positron seemed to provide just the particle to correspond to one of these "holes" in space. The correspondence is indeed very close as is shown by the fact that in agreement with the Dirac theory, the fastest negative electrons had energies 1,000,000 electron volts greater than the fastest positive electrons.

This observation provides evidence for the correctness of the view put forward by Blackett and Occhialini, who on the basis of the Dirac theory suggested that the positive and negative electrons might be created in pairs out of the incident radiation. Fortunately for the physicists of today, the theory of relativity as developed by Einstein shows that there exists a very close relationship between mass and energy—so close in fact that mass and energy may be considered as two aspects of the same entity. According to this view, if a pair of electrons is created out of the gamma radiation, then an amount of energy would be used up in the act of creation depending upon the masses of the particles formed. If one take the known mass of the negative electron, and assume the same value for the mass of the

positron, then the calculated energy required for the creation of a pair of electrons comes out very close to 1,000,000 electron volts. The agreement with experiment is good, for according to this picture a negative electron can receive practically all the energy of the incident radiation; whereas a positron can appear only through the creation of a pair, hence the maximum energy it can receive is the energy of the incident radiation diminished by the 1,000,000 electron volts required to create the pair.

In plate 2, figure 1, is shown a photograph of the paths of a pair of electrons, one positive and one negative, generated by gamma rays from thorium. Repeated experiments by ourselves, including measurements on 2,500 electrons, and by Chadwick, Blackett, and Occhialini, based on 4,000 measurements, have failed to show any certain evidence that the positrons are not created along with negative electrons by the incident gamma radiation.

Calculations made by J. R. Oppenheimer and M. S. Plesset, who used the Dirac theory, have shown that the attenuation of a gamma-ray beam in passing through matter (due to the energy spent in creating electron pairs) is in good accord with observations.

This bold theory of Dirac requires further that a positron, when it finds itself in a very ordinary environment, as, for example, in passing through water, shall, on the average, have only a very short life, of the order of a billionth of a second or less; for when a positron meets a negative electron, both particles will suffer the fate of complete annihilation, and in their stead a pair of corpuscles of radiant energy, each of one-half million electron volts, will remain. Although the lifetime of positrons has not been actually measured, it has been shown to be very short, and the "annihilation radiation" announcing their death has been observed. The first to do this were Joliot and Thibaud. The annihilation radiation is of the proper intensity and the energy of its individual corpuscles is approximately the required amount of one-half million electron volts, corresponding to the complete annihilation of the positrons. There is no reason to believe, however, that a positron, if removed from a region densely populated by negative electrons, may not live hundreds of millions of years, instead of perishing in a billionth of a second.

The exact relationships among the four primary particles, the negative electron, the positron, the proton, and the neutron, are at present not known. It appears quite plausible that under certain conditions a negative electron and a proton may be formed out of a neutron; and similarly a positron and a neutron may be formed out of a proton.

A photograph showing the paths of a shower of positrons and negative electrons ejected from a plate of lead by cosmic rays is presented in plate 1.

THE DEUTON

Spectroscopy, the study of light emitted by atoms under various conditions, has during the past several years played a major role in unraveling the mysteries concerning the behavior of the extranuclear electrons. In 1931 it was responsible for a discovery of the first magnitude in the realm of nuclear physics. The wave length of the light emitted by an atom depends upon the energy change involved when an extranuclear electron transfers its position from one orbit to another. The amount of this energy change is determined, of course, chiefly by the charge upon the nucleus about which the electron revolves. The electron does not in fact revolve about the nucleus as a center; but both nucleus and electron revolve about their common center of gravity. Hence the size of orbit, and therefore the wave length of the light emitted, depend in some measure upon the mass of the nucleus, as well as upon its charge. H. C. Urey, G. M. Murphy, and F. G. Brickwedde, early in 1932, in photographing the spectrum of hydrogen, observed in addition to a well-known bright red line of hydrogen a faint line slightly displaced. These men correctly interpreted the new line as showing the existence of a new kind of hydrogen atom, a new isotope of hydrogen, to the nucleus of which the name "deuton" has been given. All hydrogen nuclei had previously been considered to consist simply of a single proton. Here, as measurements on the displaced line showed, was evidence of a new hydrogen nucleus having approximately twice the mass of a proton, and constituted presumably of a proton and neutron in close combination. The chemical properties of an atom depend upon the number of extranuclear electrons and therefore upon the nuclear charge and not upon its mass. The new hydrogen, to which the name "deuterium" was given, forms water by combination with oxygen in a manner exactly identical with the well-known oxidation process of ordinary hydrogen into water. The new water, or "heavy water", chemically is pure water; but its physical properties, such as density, boiling and freezing points, differ slightly from ordinary water.

Heavy water can be conveniently prepared simply by passing an electric current through ordinary water until only a small residue of the water is left. Ordinary water contains normally about 1 part in 5,000 of heavy water. By continued electrolysis this concentration can be increased to any desired extent. Heavy water, 99 percent pure, was first prepared by G. N. Lewis, and is now sold in the market as a commercial product. To the nuclear physicist, deutons, obtained from heavy water, have become exceedingly valuable as projectiles in the bombardment experiments to be described. Here,

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therefore, is an example of a discovery in pure science which almost immediately found a practical application in furnishing to the nuclear physicist a very efficient projectile just at a time when such ammunition was to become exceedingly valuable.

ARTIFICIAL ATOMIC TRANSMUTATIONS

Fundamentally, the method of effecting atomic transmutations is to allow one nucleus traveling at a high velocity to strike another nucleus and then to watch for evidence of a transmutation. Rutherford, in his first work in 1919, used the alpha particles emitted by radium. The alpha particles, or nuclei of helium atoms, were allowed to strike nitrogen nuclei; and the ejection of protons, or hydrogen nuclei, was observed. In the following years the work in this field progressed only slowly, chiefly because of the limitations imposed upon the method by the need of relying upon natural radioactive bodies to supply the projectiles. The scarcity of radioactive materials and the minute size of the nucleus target, which permitted only one in more than a million of the alpha particles to make a hit sufficiently direct to produce a transmutation, made the number of transmutations which could be effected by this method very small indeed.

But in April 1932 the experiments of J. D. Cockcroft and E. T. S. Walton in the Cavendish Laboratory, England, gave a tremendous impetus to this fascinating and important phase of physics. In place of Nature's own source of high-speed nuclei they substituted a large glass tube in connection with a high-voltage electrical circuit and observed for the first time atomic disintegrations produced by ammunition artificially flung. The electrical method of producing high-velocity streams of particles has the advantage that one is not limited only to alpha particles such as radium supplies but may also use various other nuclei. Cockcroft and Walton first used protons. The newly discovered deuton has proved to be a projectile par excellence and is now a favorite among the atom smashers.

The speed given to the projectile depends upon the voltage applied to the tube. The first work was done using 700,000 volts; and, although it is not necessary to use voltage of such high values, the effectiveness for transmutation increases rapidly with voltage—the higher the voltage the more transmutations produced. The voltages employed, and the currents, which determine, respectively, the speed and the number of projectiles fired per second, are limited only by the technical difficulties involved. Already these have been overcome to such an extent that in this country, C. C. Lauritsen and R. H. Crane at the California Institute of Technology are using daily a tube operating at close to 1,000,000 volts and employing

sufficiently large currents to send more than 2,000,000,000,000,000 protons or deutons into the target per second, at speeds in excess of 10,000 miles per second.

Lauritsen and Crane use a 1,000,000-volt power transformer set to speed up their bombarding particles, but two other workers in this country have developed quite ingenious methods to achieve the same end. The first of these, operating in an extremely unique fashion, was developed by E. O. Lawrence and his collaborators at the University of California. This method consists essentially of the successive application, at accurately timed intervals, of relatively low accelerating potentials to the particles, each particle being accelerated in many steps until it has attained a high velocity. A radiofrequency oscillator is employed to furnish the timed accelerating pulses; and in one form of their apparatus, the whole accelerating chamber is placed between the pole pieces of a large electromagnet. The action of the magnetic field causing the particles to travel in circles, they thus return at regular intervals to receive another boost by the oscillating electric field until they are taken out for use near the periphery of the accelerating chamber. Through this means particles have been given energies up to some 4,000,000 electron-volts, the highest energy particles so far produced by laboratory means and used for atomic disintegrations.

Another form of apparatus planned to produce particles of still higher energy is now under construction at the Massachusetts Institute of Technology. Designed by Van de Graaff, this device is essentially an elaborate modification of the familiar electrostatic machine. It has already produced in preliminary tests potentials of about 7,000,000 volts. The harnessing of potentials of this magnitude to the speeding up of atomic particles is a technical problem of extreme difficulty. The Massachusetts group has not as yet applied these voltages to atomic transformations. When successfully harnessed, such voltages will no doubt extend considerably this work in the "chemistry of the nucleus", in which new elements are built up out of old in a manner much like the building of chemical compounds out of the elements by the chemist.

Working in Washington, D. C., M. A. Tuve, L. R. Hafstead, and O. Dahl have successfully used for many varied experiments in atomic disintegrations a Van de Graaff generator built on a smaller scale and operating at 2,000,000 volts.

All cases of nuclear disintegrations so far studied, whether they are stimulated by natural projectiles from radioactive bodies or by the much stronger projectile-beams produced artificially, show pronounced differences from the ordinary chemical reactions studied by the chemist. The first difference is that in the nuclear reactions the

number of individual atoms entering into the reaction is smaller by many orders of magnitude than those ordinarily involved in chemical reactions. The second is that for each atom that is involved the nuclear reaction is much more energetic, an amount of energy being often liberated which is a million times greater than that liberated by the most violent chemical reaction, as, for example, by the explosion of dynamite. Because the atoms involved in the nuclear reactions are so relatively few in number the most sensitive and elaborate forms of physical apparatus must be employed for their detection; but, fortunately, owing to the extremely high energies given to the particle in such reactions, it is often possible to count and measure, individually, single atoms formed in the disintegration.

A further consequence of the small number of atoms participating in a nuclear reaction is that the total amount of a new element that can be produced is extremely minute. This is illustrated by the fact that if today's most efficient apparatus, adjusted to produce helium out of lithium and hydrogen, were operated continuously for 100 years it could produce at the best only a fraction of a penny's worth of helium, whereas the power cost would approach $1,000,000. The physicist has not as yet learned how to produce new elements in bulk.

INDUCED RADIOACTIVITY

In 1934 Curie and Joliot reported the fact that many of the light elements, after bombardment by alpha particles, were found spontaneously to emit positrons. After the alpha-particle bombardment ceased, the emission of positrons continued. Curie and Joliot had found how to make inert substances radioactive; and, appropriately enough, the daughter of the discoverer of radium becomes the co-discoverer of artificially produced radioactivity. This discovery is of far-reaching scientific importance, and today, less than a year after its announcement, radioactive substances artificially produced have already shown promise of competing favorably with the rare and expensive natural product, radium.

The technique of producing artificial radioactive substances is quite simple. One has merely, for example, to hold a few crystals of boric acid close to a radioactive substance which emits alpha particles. Some of the alpha particles, in striking nuclei of the atoms of boron in the boric acid crystals, will effect a transmutation; and a new element, nitrogen, is born. Nitrogen is an exceedingly common element, comprising as it does four-fifths of the earth's atmosphere; but the nitrogen produced in the boric acid differs from the familiar nitrogen of the atmosphere in one very important respect. It contains in its nucleus one neutron less than does the everyday nitrogen and has therefore an atomic weight of 13 instead of 14.

This difference is sufficient to render the nucleus of the new nitrogen, or radio-nitrogen as it is called, unstable; and it subsequently disintegrates by the ejection of a positron, after which a stable atom of carbon remains.

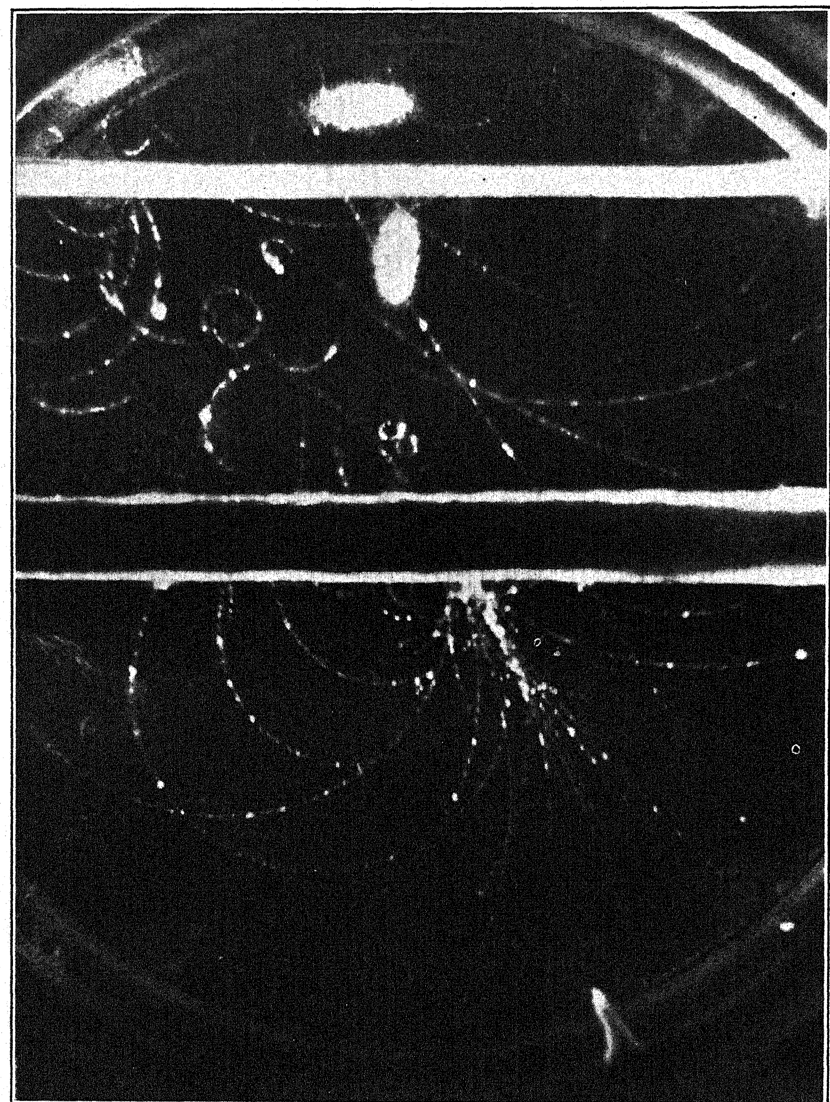
The high-voltage tubes and other devices previously described for speeding up atomic particles have proved very effective for the production of artificial radioactivity, and a great variety of new radioactive elements have been formed and studied. Plate 2, figure 2 shows a photograph of the paths of positrons ejected from carbon after it had been subjected to bombardment by deutons.

The activity of the artificially stimulated substances decreases with time in a manner similar to that of the natural radioactive products. Most of the artificial radioactive substances so far produced have a half-life—the time required to decrease the activity to half value—which varies from a few seconds to several hours, depending upon the element produced. Recently the emission of negative electrons as well as of positrons has been observed; and, in at least one case, a gamma ray is emitted.

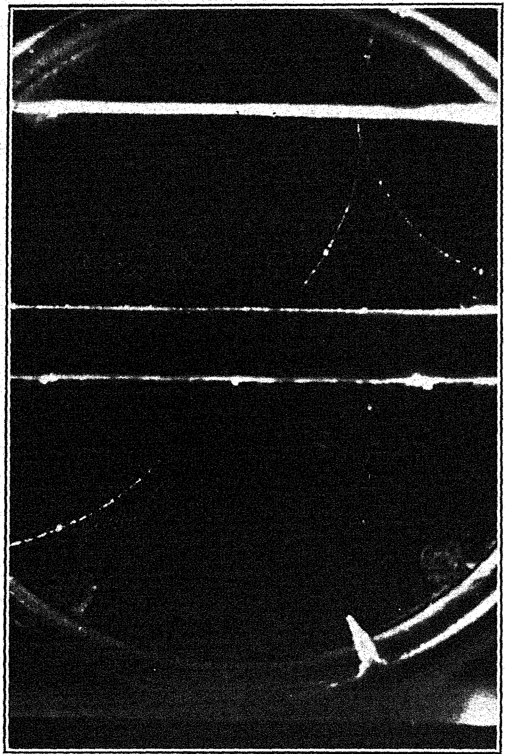
Although most of the light elements of low atomic weight have yielded to atomic transmutations, the disintegration of the heavy elements by bombardment with electrically charged particles such as protons, deutons, or alpha particles, so far remains unaccomplished because of the exceedingly strong electrical forces which must be overcome before a charged particle can enter a nucleus. The successful disintegration of the heavy atoms by this means would require the application of exceedingly high voltages, unattainable by present-day technique.

Within the past few weeks, E. Fermi, working in Rome, has succeeded in inducing radioactivity through bombardment with neutrons. Working with a large number of elements, he found that the heavy elements yielded as readily as did the lighter ones. Since the neutron has no net electric charge, the intense electric fields surrounding the nuclei of the heavy atoms provide no protection whatever against neutron bombardment.

So today practically the whole series of the 92 elements has been disintegrated in one manner or another; and dozens of new isotopes have been formed, the majority of which are radioactive. It now appears quite likely that any element by proper treatment can be prepared in a radioactive condition, and the years to come will undoubtedly find widespread tasks for them to perform.

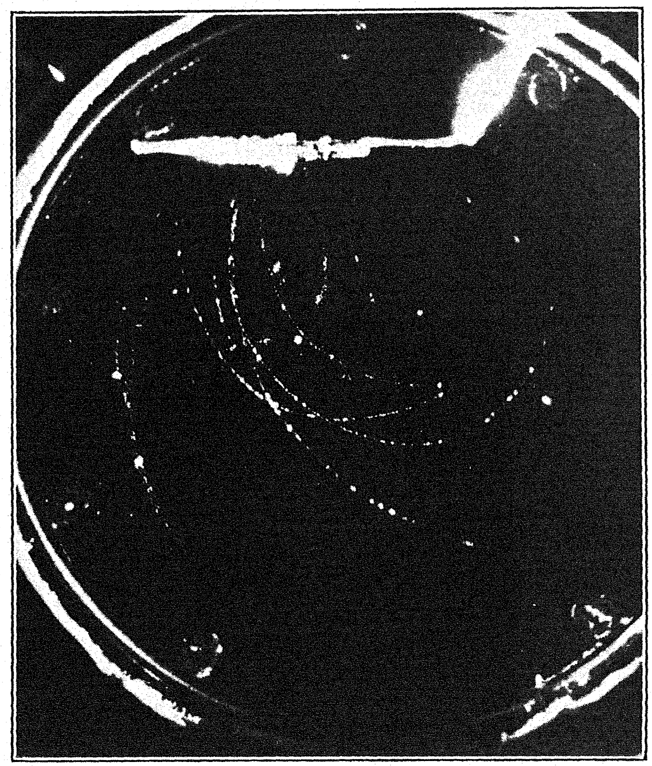


AN ENERGETIC SHOWER OF POSITRONS AND NEGATIVE ELECTRONS PRODUCED BY A COSMIC-RAY PHOTON STRIKING A PLATE OF LEAD.



1. PATHS OF A PAIR OF ELECTRONS, ONE POSITIVE AND ONE NEGATIVE, EJECTED DOWNWARD FROM A PLATE OF LEAD BY GAMMA RAYS

In the upper right-hand region of the photograph the positron path is seen to curve toward the right, and the negative-electron path toward the left.



2. PATHS OF POSITRONS EMITTED BY AN ARTIFICIALLY PRODUCED RADIOACTIVE SUBSTANCE.

THE APPROACH TO THE ABSOLUTE ZERO OF TEMPERATURE[1]

By F. SIMON, D. Phil.
Clarendon Laboratory, Oxford University; Formerly Professor of Physical Chemistry at Breslau

[With 1 plate]

Speaking in this building, with all its associations with low temperatures, a long introduction would be superfluous, but I would like to remind you of some data. In figure 1 a temperature scale is given in degrees Centigrade, and you see some important fixed points marked on it.

Now is this scale infinite at both ends or not? We know that heat consists in the unordered motion of the smallest particles, the atoms or the molecules, and the intensity of this irregular motion rises with increasing temperature (in an ideal gas it is directly proportional to it). So it is evident that there will be no limit to high temperatures, as there is none to the intensity of the motion, but, of course, there will be a lower limit to the temperature scale, at the point where the thermal motion stops altogether. This point is therefore with justification called the absolute zero. Though it has not been reached in experiment, and as we will see later on, it is by principle impossible to reach it absolutely, its position can be given with great accuracy, and it is found to lie at −273.1° C. A rational temperature scale has, therefore, to begin at this point. In this scale, the Kelvin scale, the absolute zero of temperature is given by the number zero, and any other temperature by adding 273.1° to the number of degrees Centigrade. On the right-hand side of figure 1 the temperatures are indicated in degrees Kelvin, and you see that the boiling point of the most volatile gas, helium, lies about 4° from the absolute zero. In figure 2 you see the liquid helium range given in more detail. By reducing the pressure over the liquid helium, one can easily get down to about 1°. By improving the isolation, and using a huge pump, Keesom succeeded in reaching 0.7°, which was the lowest temperature obtained until a few years ago.

[1] Reprinted by permission from Royal Institution of Great Britain Weekly Evening Meeting, Friday, Feb. 1, 1935.

I will begin by showing two experiments. The first is the production of a high temperature. It is a very simple experiment that you have all done yourselves. I need only switch on an electric lamp. By varying the current I get temperatures up to 2,500°.

In the second experiment I will generate a very low temperature, and that is much more complicated. While I could certainly perform the first experiment without any help, the second would be impossible without the kind help of Mr. Green, Dr. Kürti, Dr. London, and the staff of the Clarendon Laboratory, who have all helped in its preparation. We will now liquefy helium, making use of a

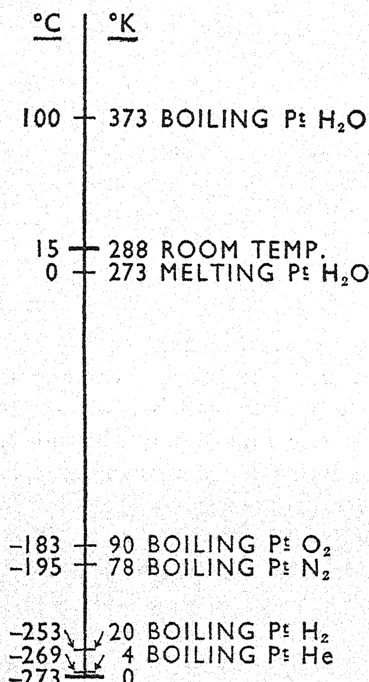


FIGURE 1.

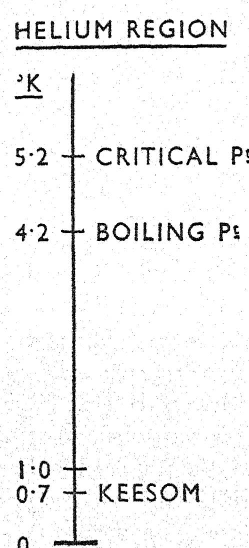


FIGURE 2.

principle about which I will say something later. Now, I should like to point out that we start at a temperature obtained with solid hydrogen (about 12°), that within the apparatus there is helium compressed to about 100 atmospheres at this temperature, and that the helium will be expanded into a balloon, where we will store it. During the expansion the helium will liquefy and reach its boiling temperature, 4.2°. As the helium is enclosed in a metal vessel, I will not be able to show it to you, but even if I could, it would not look a bit colder than liquid air. This simplified gas thermometer gives you a much better measure for the temperature. You saw that it pointed first to 12° then, as the helium was expanded and this

balloon filled, the temperature fell to about 4°. I can also show you another proof that we have reached the temperature region of liquid helium.

You have all heard of supraconductivity. This is the name given to the phenomenon discovered by Kamerlingh Onnes, that at certain temperatures some metals lose their electrical resistance altogether. The temperatures at which this happens are very low; they all lie below 10°. In a normal substance a current once induced would disappear very quickly, as its energy would be absorbed within about 1/1,000 of a second by its resistance. In the case of a supraconductor, however, there is no resistance, so that the current goes on flowing indefinitely.

In this lecture room, Professor McLennan [2] showed you this phenomenon of a persistent current in a lead ring, which was brought from Leiden immersed in liquid helium, so I need not speak about it in detail now. For the moment we will only use it to show that we really have the temperature of liquid helium. For this purpose a lead ring is fixed within the apparatus. Lead becomes supraconductive at about 7°, so that now at 4° it is already in the supraconducting state. We will now induce a current within this ring.[3]

Before the current was induced a magnetic needle was not affected. Now, you see that when I hold it a little above the ring it points with its N. pole toward it. This indicates that there is a S. pole of the magnetic dipole corresponding to the persistent current. Bringing it below the ring, it naturally changes its direction.

I can show you the existence of this current in yet another way. I have here a small coil connected with a galvanometer. When I bring it up to the apparatus, you see a ballistic deflection of the galvanometer. This is due to the cutting of the magnetic lines of force originating in the persistent current, and the magnitude of this ballistic deflection is a measure of the intensity of the current. So we have here a quantitative measure for the current, and we will verify at the end of the lecture that it is steady.

You see the great difference in outlay for the two experiments. For generating 2,500° you have only to connect an electric lamp to the mains; for generating −270° you have this decidedly complicated apparatus—and yet this is certainly the most simple one in existence. And we have not yet even taken into account that in the second experiment we did not start at room temperature, but at −260°. This temperature was obtained by hydrogen which we liquefied in the plant in the Clarendon Laboratory in Oxford, and

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[2] Proc. Roy. Inst., vol. 27, p. 446, 1932.

[3] This was performed by switching on a magnetic field, higher than the threshold value of lead at this temperature, so, with the field on, no persistent current flowed; reducing the field, a current is induced, which now persists as the substance is in the field zero.

the liquid nitrogen necessary for the hydrogen liquefaction was generated in yet another plant. For the first experiment, on the other hand, I could get the whole plant in my hand by taking a torchlight.

Now, what makes this big difference? Heat is due to the irregular motion of the smallest particles. So to heat a substance means to increase its energy but still more to increase the internal disorder of its particles. To cool down a substance means to diminish its energy but still more to increase the internal order of its particles. For example, a gas is in a very big state of disorder, the atoms flying in all directions about the space according to their kinetic energy, which is proportional to the temperature. Cooling it down, it will first liquefy, and a liquid is already a much more ordered system than a gas. Cooling it still further, it will solidify; now all the mean positions of the particles are given by a crystal lattice, and the system is in a state of nearly perfect order, only the thermal vibrations of the atoms around their mean positions being still a source of some disorder. Cooling down still further, even this disorder vanishes more and more.

So cooling a substance means bringing it into a state of order, and it is always much easier to make disorder than to establish order. Although you are certainly very familiar with this fact, I will illustrate it by an example. On this tray I have arranged these black and white balls in order. It is very easy now to establish a disorder by shaking the tray, but it is impossible to establish any sort of order again by shaking, or, to speak more precisely, the probability of succeeding is extremely small. Of course, I can establish an order by selecting the balls with my hands; but in the case of a system consisting of atoms, this is obviously impracticable and, by principle, impossible, too. We have only macroscopic means at our disposal. This difficulty of creating order is just what makes the big difference. And this is why, even 10,000 years ago, men were able to generate very high temperatures—sufficient for melting metals—but the low-temperature technique is of a quite recent date. Even the ice-cream industry is fairly new, though the temperatures involved are not very much below room temperature.

To generate heat one must, of course, have energy at one's disposal, but to transform this energy into the disordered form of heat energy presents no difficulty at all. We saw this in the electric lamp, but one can do it in a great many other ways; for instance, in a candle it is a chemical energy we transform into heat energy, in the brakes of a car it is a mechanical one.

If our example with the balls were absolutely analogous it would be impossible to generate a low temperature at all, but luckily it is

not so, because, unlike our analogy where the order depends only on one variable, in a real physical system it depends on many more. The most important quantity it still depends upon is the volume. Taking the probability of finding an atom within a certain region as a measure for the state of order respective to the positions in space, it is quite evident that this probability decreases on enlarging the space the atom has at its disposal. So in a diluted gas we have a great disorder; if it is compressed to a small space, its order is increased.

Now thermodynamics has given us a quantitative measure for this state of order of which we have to speak so much now, since it is necessary for understanding things later on. This measure is called the entropy. I will not trouble you with this quantity, as I know it is not a very popular one. I only want to remind you that it is a measure for the state of order, and that there is a law, namely, the second law of thermodynamics, which tells us that within a closed system during any change the entropy can only increase, or at the best by making a reversible change (that means avoiding unnecessary disorder) it can remain the same. Speaking in our terms now, this second law means that in a closed system the state of order can only decrease or at the best remain constant.

Let us see now what this has to do with generating low temperatures. We will take a cylinder with a piston, containing a gas, the whole system being perfectly isolated from its surroundings. The state of order in this system consists of two parts, one depending on the temperature and the other on the volume. Compressing the gas, we increase the state of order corresponding to the volume. As the whole state of order must remain the same, the disorder due to the thermal motion has to increase; that means the temperature rises, and you all know that in compressing a gas it heats up, this heat being called the compression heat.

Bringing this system into thermal contact with its surroundings, it will cool down to the initial temperature, and so its disorder becomes smaller. But, of course, that does not contradict the law I spoke of before, because heat is transmitted to the surroundings, so increasing the disorder of the particles there.

Now we will isolate the system again and pull the piston out. The part of the disorder due to the volume increases again. The whole state of order must remain constant, so the part of the disorder due to the temperature must fall, and that means the temperature itself falls.

That is a characteristic example, and one of the most important cases of how to generate a low temperature. Generally speaking, whenever one wants to lower the temperature, one must have a

system in which the state of order can be changed by some external means. Then in the way described above, one is able to transmit a part of the original disorder in the system to the surroundings, and to cool it down, making the same change of this variable in the opposite direction after having isolated it from the surroundings.

Gases are the prototype of a disordered system, the existence of which is necessary for the procedure of generating low temperatures, and it is relatively easy with them to change this disorder by changing the volume. So practically all procedures for generating low temperatures were worked with gases until recently. Of course, one can make use of them only down to the temperatures at which they liquefy, or more precisely, as long as their vapor pressures have still practicable values. So in practice the generation of low temperatures and the liquefaction of gases have become practically identical conceptions, and every step toward a lower temperature has been marked by the feat of liquefying a gas with a lower boiling point than was previously possible.

I will not speak now of the development of the real procedures performed with gases in order to liquefy them, which, for technical reasons, have to be much more complicated than the example I gave you. I need only remind you of the names of Faraday, Cailletet, Pictet, Olzewski, Linde, Hampson, Dewar, Claude, and Kamerlingh Onnes. You know that it is now relatively easy to get down to the temperature of liquid air, as the liquefaction of air has become important for industrial technique. But I want to mention that to cool by one calorie at even such a relatively high temperature as that of liquid air is already 500 times as expensive as to heat by a calorie above room temperature; for instance, by burning benzine. But at lower temperatures the difficulties increase enormously, so that the use of liquid hydrogen has been restricted to a few laboratories and that of liquid helium to still fewer big specialized laboratories.

In recent years the study of the properties of matter at very low temperatures has become increasingly important; and so, of course, one has sought for ways of simplifying the low-temperature technique. We have in the last few years developed a comparatively simple method for liquefying helium, which I have shown you already, and now I should like to say a few words about it. The procedure of expanding a gas in a cylinder, in the way already described, is very simple. But at the very low temperatures it is difficult to realize technically a cylinder and a piston.

But one can overcome this difficulty in a very simple way, which I will now explain. In figure 3, A, we have a gas enclosed in a cylinder with a piston. Upon pulling out the piston the gas will cool down. In figure 3, B, you see the cylinder divided into two

parts connected by a tube. Upon pulling out the piston now the gas will cool everywhere because this cooling is a homogeneous procedure. Let us cool now only the lower part to the low initial temperature, at where we start (for example, to the temperature of liquid hydrogen if we want to liquefy helium), leave the upper part at room temperature, and pull out the piston again. Then the gas will cool down within the lower part the same as if the upper part were at the low initial temperature too. The atoms in the lower part do not know whether the upper part is hot or cold and the atoms do not know either if there is a cylinder and piston outside.

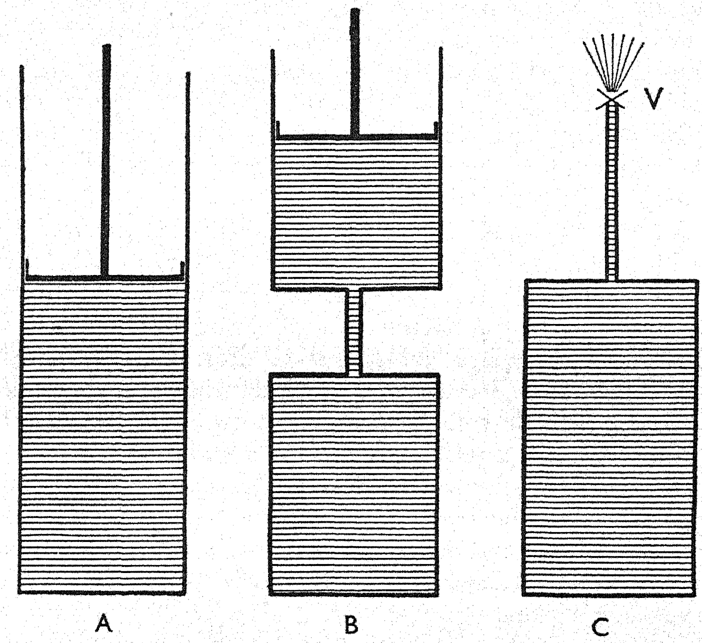

FIGURE 3.—Principle of the expansion method.

We get the same effect if I simply let it out by a valve, as in figure 3, C. I want to emphasize that the cooling arises within the cylinder, and not at the valve, as in the Linde process. The procedure described above has nothing to do with the Linde process, but it has more resemblance to the Cailletet method. You remember, perhaps, that he let a gas expand in a glass capillary tube, and with some of the so-called "permanent gases" he could then see a little dust of liquid drops, indicating that for some fraction of a second the temperature had fallen considerably.

Now, starting at high temperatures, the cooling effects obtained in this way are very small. The chief reason for this is that a container for high pressures has, at room temperatures, a heat content that is

always big compared with that of the gas. Starting at low temperatures, however, the situation changes absolutely. Firstly, one gets a much bigger amount of gas into the container at a given external pressure, according to the gas laws, and secondly, the specific heats of all solid bodies drop with temperature, disappearing on approaching absolute zero. So for instance, at a temperature of about 12°, 1 cubic centimeter of helium gas compressed to 100 atmospheres has the same heat capacity as 1 kilogram of copper. This means we can neglect the heat capacity of the walls altogether, and we have the advantage of working with mathematical walls. Thus, the efficiency of the procedure, as I described it to you, becomes very high, and working with suitable dimensions and a good isolation, it is easy to keep the low temperatures, too. For instance, under the conditions realized in this apparatus, about 60 percent of the volume originally filled with the compressed helium remains filled with the liquid phase, and in the apparatus we generally use we can raise this efficiency still much higher.

In this way one could liquefy any quantity of helium. But as the specific heats at low temperatures are so very small, only tiny amounts of liquid helium are really necessary for cooling down the apparatus and making measurements for a number of hours, if the apparatus is designed in a suitable way. For example, in this apparatus we have liquefied about 50 cubic centimeters, which is sufficient to cool down the whole system and to work for about 5 hours.

In figure 4 you see a rough plan of the apparatus. Outside is the vessel D with liquid hydrogen; inside, the space S that is evacuated. Within this you see the container C that is first filled with compressed helium, and after the expansion with liquid helium. Attached to this container is a gas thermometer G, the readings of which you saw before.

To cool the apparatus down further, one could reduce the pressure over the liquid helium; the temperature must then fall till it corresponds with the vapor pressure of the helium. For purely technical reasons we do not do this, but we have a second vessel E that we can fill with liquid helium by letting helium gas through the tube T. Then it condenses in the tube T where it is in contact with C, and drops down into the vessel. By pumping through T now, we reduce the vapor pressure, and therefore the temperature falls. This vessel and the surrounding Dewar vessel are of this peculiar shape because we will afterwards apply magnetic fields to some substance situated in the vessel, and, of course, one can generate strong magnetic fields over a small distance more easily than over a big one. Now, we will pump off the helium in this vessel, in order to reduce the temperature here, and the temperature will fall below 2° within a short time.

Before we consider the methods of generating still lower temperatures, I want to refer briefly to the measurements of these temperatures. You know that, in general, one measures temperature by the pressure of a diluted gas, using it as a substitute for an ideal gas. But at the lower limit of the liquid helium range the only existing gas, the helium, is stable only at a pressure so small that it is of no use for a thermometer. In this region one can use another phenomenon for measuring the temperature.

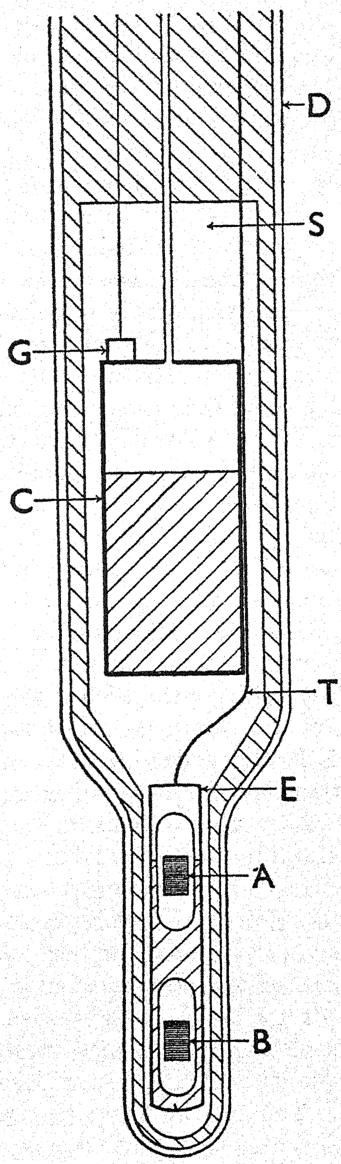

FIGURE 4.—Simplified diagram of the apparatus.

The thermometer that I want to speak of now is a magnetic one, and it depends on the fact that paramagnetic susceptibility is a function of temperature. In a paramagnetic substance there exist little elementary magnets, which we will assume for the moment to be perfectly free to point in every direction in space. The thermal agitation has the effect of making the directions of these elementary magnets have a random distribution. Applying a magnetic field, it will try to turn them in its direction; on the other hand, the thermal agitation tries to establish a disorder with respect to the direction of the dipoles. There will be a compromise of these two effects, and it is evident that the lower the temperature, that means the lower the thermal agitation, the more magnetized the substance will become. Calculating this numerically, one finds that in such a substance the magnetic susceptibility would be proportional to 1/T. That is the famous Curie Law, which was derived primarily for paramagnetic gases, because there the single elementary magnets connected with the atoms or molecules are certainly perfectly free. At first sight one might think that within a solid body the condition of free elementary magnets could not be realized. But experiments, made chiefly in the Leiden Laboratory, have shown that there are some paramagnetic salts which follow

Curie's Law down to the helium temperatures with great accuracy, and this means that the elementary magnets within them have a very high degree of mobility. The salts concerned are especially those of the rare earth and iron groups. I cannot go into a theoretical explanation of this behavior, but I want to mention that it is in accordance with our theoretical ideas.

So it is easy to construct a thermometer with such a paramagnetic substance, using its susceptibility as a measure for the temperature. And it is evident that a thermometer of this kind becomes very sensitive at low temperatures. For example, between 4° and 1° the susceptibility changes in the proportion 1:4. We have a thermometer of this kind in our apparatus. We measure the susceptibility by bringing a system of two coils around the place where, inside the apparatus, the salt is situated, and sending an alternating current through the primary coil; the induced e. m. f. in the secondary depends on the susceptibility of the salt which is fixed within these coils. This induced e. m. f. is amplified in a little set (which the Cambridge Instrument Co. have very kindly lent me for the demonstration); then it is rectified and sent to a galvanometer that shows the deflections on this scale. Of course, the system is compensated in such a way that the deflection zero corresponds to a susceptibility zero within the coils. Thus the deflections on the scale are a direct measure of the susceptibility, and as this changes with 1/T, the deflections are proportional to 1/T. At the moment the thermometer is showing about 2°.

Now we can continue considering how to approach nearer to the absolute zero. As I have mentioned already, the lowest temperature reached by reducing the vapor pressure of liquid helium is 0.7°. At this point the vapor pressure is so small that it is in practice impossible to proceed further. A gas with a still lower boiling point does not exist. Very probably the new helium isotope, helium 3, discovered in the Cavendish Laboratory, will be more suitable for reaching low temperatures, if it can ever be obtained in sufficient quantities, but there will be no difference in the order of magnitude.

You may be wondering why we should bother to get still nearer to absolute zero, as it seems so difficult now to get down any further. What can still happen in this small region? To answer this question we have to ask another. When can one predict that something will happen in a certain temperature region?

Let us assume that the phenomenon we are interested in is connected with an energy change of a certain quantity. Then the thermal agitation will have an influence on it when it itself reaches this order of magnitude. So we see that from this point of view there is no sense in speaking of an absolutely high or an absolutely

low temperature; it is always necessary to compare it with the phenomenon in which we are interested. For instance, room temperature is a very low temperature if we look for the evaporation of diamond, because its heat of evaporation is very high (i. e., only at high temperatures is the thermal agitation big enough to push a carbon atom out of the crystal). But room temperature is a very high temperature if we look for the evaporation of hydrogen, as its heat of evaporation is very small. So the question is, are there any phenomena connected with very small energy changes; that means, phenomena which will still happen at very low temperatures?

If the atoms were only points possessing attractive or repulsive forces, then certainly nothing much of interest would happen within the new region. The thermal agitation would become smaller, but this would not give rise to any new phenomena. However, we know that although in the kinetic theory it was for a long time sufficient to treat the atoms as points with attractive and repulsive forces, yet this is certainly not a complete picture. We know that the atoms are built up from nuclei and electrons. In general one is accustomed to find the effects of this complexity of the atoms only in gases at high temperatures, as most of them are connected with big changes of energy. It is true that at normal temperatures the effects originating in the complexity of the structure of the atom are not very striking in a solid body, but certainly some do exist. For instance, we spoke just now of the magnetic properties of some salts. If the atoms were only points with forces, they could not show any magnetic properties. These are due to the motion or the spin of the electrons, and here we have one effect of the structure of the atom. We have seen already that this effect becomes more and more striking as the temperature is lowered. We have also considered another phenomenon that would not have been possible if the atoms had only been points. A system of points could not show metallic conductivity. That is due to electrons split off the atoms within the metal, and we have seen that with these electrons, something happens only at very low temperatures, namely, supraconductivity. Here some change takes place connected with an energy difference of such an order of magnitude that it becomes equal to the thermal agitation only at very low temperatures; and I may mention that at present it is not known what exactly is happening in the metal.

It would be very important to see whether at still lower temperatures all metals become supraconductive; that is, whether it is a general property of all metals.

So we see that it is of interest to extend our temperature range to lower temperatures, and we will find later on that there are still more phenomena that can be expected to take place below 1°.

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But in order to go lower, how can we proceed? As we discussed before, to get a low temperature one must have a system at one's disposal which is still in a big state of disorder, and one must be able to change this disorder by changing an external variable. At these temperatures we no longer have gases. What other disordered systems still exist? Well, we have just seen one, namely, the paramagnetic salt which still follows Curie's law; and about 10 years ago Debye and Giauque proposed using this for the generation of still much lower temperatures.

To understand the principle, look at figure 5, which represents a paramagnetic salt. The circles represent the atoms arranged in a crystal lattice, and the little arrows represent the magnetic moments attached to every atom. Without a field (fig. 5, A) there exists, as we saw before, a random distribution of the directions of the

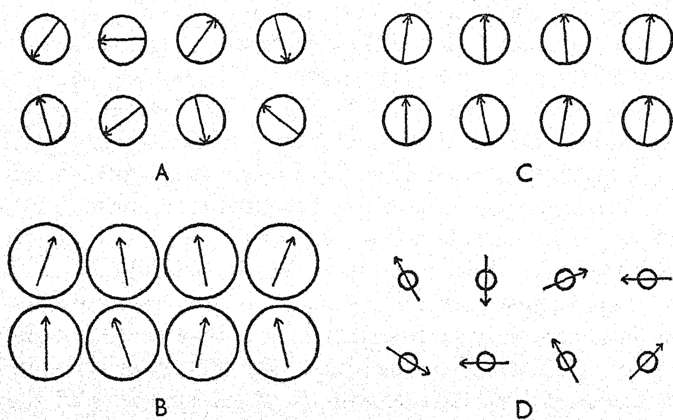


Figure 5.—Principle of the magnetic cooling method.

dipoles, so the disorder in this system consists of two parts; one is due to the distribution of the directions of the dipoles, and the other to the thermal motion of the atoms. (The diameters of these circles indicate the magnitudes of the vibrations and give also in this way a measure for the disorder due to the thermal vibrations.) Applying the field now (fig. 5, B) it will try to order the directions of the dipoles. Making it adiabatic—that is, having the system isolated thermally from its surroundings—the whole state of order should remain constant, which means that the disorder due to the thermal movement must increase, in other words, the temperature rises (corresponding to the compression of the gas in our former example). Making heat contact with the surroundings, the system cools down to the initial temperature, so that now the state of order has increased (fig. 5, C). Now, isolating the substance from the surroundings and taking the field away, the dipoles try to distribute their directions at random again, the disorder due to this

increases, but as the whole state of order must be constant the temperature must fall (fig. 5, D). (Corresponding exactly to the adiabatic expansion of the gas.)

Within the last few years this method has been used experimentally, and at nearly the same time Giauque and MacDougall in California, de Haas and Wiersma in Leiden, and Dr. Kürti and I began to work with it. We developed the technique so that it is now fairly easy to work with this procedure, and we can show you an experiment with it here in this room.

We will look once again at figure 4. There you see within the lower vessel two different paramagnetic salts A and B, so that we can do two different experiments. To carry out the cooling by this method one has to have the substance in thermal contact with the surroundings when the field is switched on and isolated when the field is switched off. We do this automatically by suspending the substance in a little glass tube closed at both ends and filled with about 1 cubic centimeter of helium at room temperature. This gas makes a heat contact with the surrounding helium bath during magnetization. Upon switching the field off the substance cools quickly, and the helium gas has to condense on it, as the vapor pressure falls rapidly with falling temperature. Choosing the right dimensions and vacuum conditions, one can in this way use the cooling substance itself as a pump.

Now we will begin with an experiment,[4] taking first the upper substance, A, manganese ammonium sulphate. We bring the magnet into position and switch on a field of about 10,000 gauss. We have to wait now for about a minute until the heat of magnetization is carried away. Next we remove the magnet and bring the coils for the temperature measurement into position. The substance has cooled down, the thermometer points to about 0.25°. At the same time you notice that the temperature keeps quite steady.

We will now make another experiment with the lower substance, B, iron ammonium alum, and the same field. We have now reached 0.1°, and you see that again there is hardly any change of temperature.

Now we will look at table 1, which gives the vapor pressures of helium at different temperatures. Although they have not been measured experimentally, these figures are very accurate, since we have all the necessary data at our disposal for calculating the vapor pressures according to the second law of thermodynamics. You see that at 0.1° the vapor pressure is 10^{-31}, and at 0.25 it would be about 10^{-12}, so that there is practically no gas which could transmit heat

[4] During the lecture a wire of the thermometer circuit broke, so that the experiment could not be performed. However, it was shown to a large number of the audience three-quarters of an hour later when the trouble had been repaired.

from the surroundings. At 0.5°, however, we have a vapor pressure 10^{-5}, which is no longer negligible. In this case the substance would warm up much more quickly, and so we have the paradox that it is much easier to keep a temperature below, let us say, 0.3°, than one above this temperature.[5]

TABLE 1.—*Vapor pressures of helium*

T	p (*mm*)
1.0	1.5×10^{-1}
0.7	3.2×10^{-3}
0.5	2.5×10^{-5}
0.3	7×10^{-10}
0.2	3×10^{-15}
0.1	3×10^{-31}
0.05	4×10^{-62}
0.03	6×10^{-103}

At these very low temperatures one can get any isolation one likes; for instance, at 0.03° we have a vapor pressure of 10^{-102}. The surroundings of the substance are at a temperature of about 1°, where the radiation is certainly negligible, and one can make the suspension so that very little heat is conducted to the substance. Thus we have really no difficulty in keeping temperatures as long as we like, even working with very small amounts of substances.

You saw that using different paramagnetic salts, we reached different final temperatures, which means that all substances are not equally good for this method. Of the many substances we investigated, iron ammonium alum was found the most suitable, and with it we have got down to about 0.04°, using a field of 14,000 gauss. De Haas reached 0.015° with this procedure, using potassium chromium alum, and having the huge magnet of the Leiden laboratory at his disposal.

I may remind you that the temperature of a material body in the interstellar space cannot fall below 2° or 3° K., as it always has to be in equilibrium with the stellar radiation. So you see that in this case we can realize in the laboratory a lower temperature than we can find in nature, and we can surpass the conditions found in nature in still another way. We will look once again at the table of the vapor pressures of helium, the most volatile gas existing. In the interstellar space there is a vacuum of about 10^{-22} cm Hg. You see that we have already reached this pressure in a space surrounded by a body at a temperature of about 0.15°, even when it is filled with the most volatile gas. At 0.03° the pressure would be so small that in the whole Galaxy we would not find one single atom in equilibrium with it. So, in the directions of low density and low

[5] Of course, one could establish a vacuum by means of pumps, but at low temperatures the helium is absorbed in big amounts on the walls, and it would take a very long time to obtain a sufficiently high vacuum.

temperature, we can surpass in the laboratory the conditions found in nature, whereas, in the opposite direction it is extremely unlikely that we will ever reach the high temperatures and big densities to be found in the stars.

There is not much point in generating low temperatures simply for the fun of playing among the low figures. How can one make investigations on substances other than the paramagnetic salts? The most simple way is to press the paramagnetic salt and the substance to be investigated together, so that they form a solid pill. In cooling down the salt, the substance cools with it. In this way we examined a lot of metals to see whether they became supraconducting or not, and three new supraconductors were found in the new region. Some other metals, however, did not become supraconducting down to 0.05°.

At the same time these measurements showed us still another thing. Cooling an additional substance with the paramagnetic salt and seeing how far the temperature is lowered in demagnetizing, compared with the temperature reached in demagnetizing the pure salt, one can measure the specific heat of the additional substance, and see whether anything happens within the new temperature region. If there is any change of energy within the substance that is equal to the thermal agitation in the new region, then it should be seen in these specific heats. And there is a very definite thing that must be expected to happen in this region. As is known from the analysis of the atomic spectra, there is an interaction of the magnetic moments of the nucleus with that of the electrons, chiefly the valency electron. As a result of this, the ground state of the atom is split up, and the energy difference between the different levels is of such an order of magnitude that the new temperature region is characteristic of it. We have already got some results in this direction, but it would be proceeding too far now to go into details.

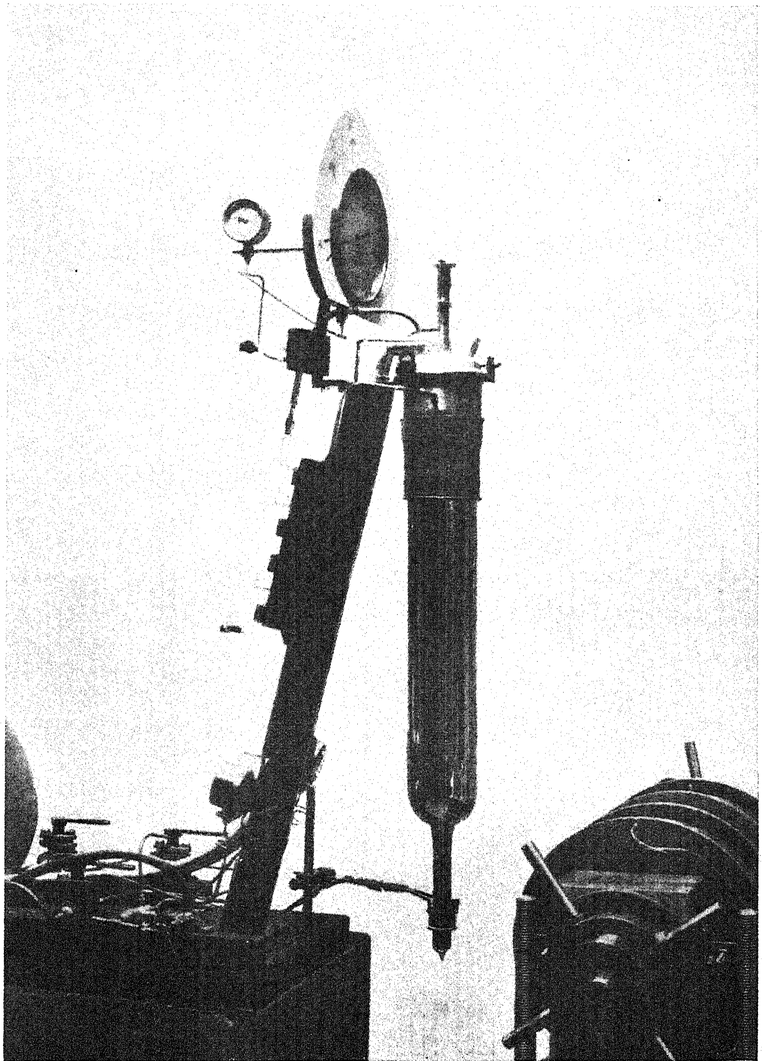
You saw that within this new temperature region there really are things that still happen, and it is not only a game with low temperature figures. One can also say that it will be both necessary and interesting to investigate temperatures lower than those yet reached.

What imposed the limit to the temperatures reached above? It should be possible to get down to any temperature if the dipoles in the salt were perfectly free, because then, even as near to absolute zero as one likes, there would be a random distribution of the magnetic dipoles, and we would always still have a means of lowering the temperature. But here the same thing happens as in the case of gases. If we had still a gas at these very low temperatures, we could certainly use it for lowering the temperature, but no more

gas exists, because there are forces between the atoms that cause the system to pass over to a state of order—the crystal—and there is no longer any disorder that we could make use of for lowering the temperature. In the paramagnetic salt the same thing happens, only at temperatures about 100 times lower. In them there also exist interaction forces which have the effect of establishing an order within the system without an external magnetic field, and so at these temperatures the paramagnetic salts cease to be of use. These temperatures differ, of course, from substance to substance, and we saw in our experiments that the manganese ammonium sulphate passed over into this state earlier than the iron ammonium alum. Of course, one could get a bit further by using still stronger magnets, but I think the practicable limit has been reached with the dimensions of the Leiden magnet.

A more hopeful way seems to be to work in two stages. That means, first work down to about 0.05°, and then, starting at this temperature, go still lower with a new procedure, like the cascade for liquefying gases, which was used so much in the past. Of course, to get to appreciably lower temperatures for the lower stage it will be necessary to find a substance in which these interaction forces, which tend to bring the system into an ordered state, are still smaller than within the substances hitherto used. I have already said that the interaction forces between the nuclear moments and their surroundings are very small, and in the second stage one will have to try to work with a substance that exhibits nuclear paramagnetism.

But even here there are some interaction forces, and so this will only work for a bit of the way to absolute zero. And with all other phenomena that may still happen in the new temperature region, it will certainly be the same. There exists a law, Nernst's Theorem, also called the third law of thermodynamics, which is confirmed by all experiments. It postulates that at absolute zero all substances are in a state of perfect order, or, in other words, that the state of lowest energy must be a state of perfect order. And we know now that this means that it will be impossible ever to reach the zero of temperature absolutely. But this does not mean that one cannot get below a certain limit, say 1/10,000°. It will be possible to reach any finite temperature, be it as small as you like. But the technique of reaching such a temperature will always be dependent on finding a phenomenon, connected with only a very small energy change, happening within a system. And so you see that this last degree, or, as we may say now, the last 1/100° to absolute zero, though absolutely very small, stretches in reality an infinite distance before us. And this infinity is not an empty one, but one that is filled with phenomena worth investigating.



THE APPARATUS.

In the middle the Dewar vessel containing the liquid hydrogen in which the helium apparatus is immersed; at the top the gas thermometer, indicating the temperature of the helium liquefier. On the thin part of the Dewar vessel are the coils for measuring the susceptibility of the salt; in the right bottom corner the magnet, which can be moved to surround the lower part of the Dewar vessel. On the left, the balloon into which the helium is expanded can just be seen.

DISCOVERY AND SIGNIFICANCE OF VITAMINS[1]

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Sir William Dunn Professor of Biochemistry, University of Cambridge

Until the end of the first decade of the present century official teaching concerning the nutritional needs of the human body was still based on the results of classical studies by Carl Voit and Max Rubner and on the views of the Munich School thence derived. The adequacy of a dietary was measured in terms of calories and protein alone. It was generally believed, alike by the academic physiologist and by those concerned with practical dietaries, that questions of palatability and digestibility apart, so long as the food of an individual provided sufficient potential energy for the activities of his internal organs and for the external mechanical work he might be called upon to do, the only demand of a more specific kind made by his body was for a certain, rather ill-defined, minimum of protein to subserve the growth and maintenance of its tissues. Beside the carbohydrates, fats, and proteins which provide these essentials, natural foods were known, of course, to contain a variety of other substances. These, however, are present individually in very small amount, and except for certain minerals among them, necessary for the formation of bone and for the maintenance of particular physical conditions in the body, they were assumed to be without nutritional importance.

Facts, nevertheless, were already known which might well have suggested that the body makes calls upon its food to supply needs more subtle and more specific than those thus recognized. The history of scurvy, for example, and the clear demonstration made already in the eighteenth century of the dramatic cure of that fell disease which follows upon suitable, though relatively very small, additions to an errant dietary, should, it would seem, have provided a strong suggestion for the existence in certain foods of a substance small in amount but with highly specific properties essential for the support of normal nutrition; that is, for the existence of what we now define as a vitamin. But, unfortunately, the views of the

[1] Reprinted by permission from Nature, vol. 135, no. 3418, May 4, 1935.

majority concerning the influence of antiscorbutic foods remained for many years vague and obscure. It was attributed to such qualities as "freshness" without further analysis of these qualities, or to known constituents without proof of their efficacy. True, so far back as 1841, an American physician, G. Budd, had ascribed the action of such foods "to an essential element which it is hardly too sanguine to state will be discovered by organic chemistry or the experiments of physiologists in a not far distant future." Had organic chemists or physiologists been then stimulated by this objective view to seek for a definite substance in such well-known antiscorbutic materials as, say, lemon or orange juice—a substance which, when isolated, could display by itself the antiscorbutic powers of these fruits—it is likely that a realization of the significance of vitamins might have come long ago; but current thought concerning nutrition was not yet prepared to profit from such suggestions.

Scurvy, of course, is now recognized as one of a group of so-called "deficiency diseases"—pathological conditions in each of which a group of symptoms is displayed, directly due to the lack of some necessary nutritional factor. It was in 1897 that evidence for the existence of another such disease was clearly revealed. Eijkman, a Dutch hygienist, had been led by extensive observations to the belief that the disease beriberi was associated with the consumption by human communities of polished rice as a basal food. He then found that it is possible to produce an illness in fowls similar to beriberi by feeding the birds on polished rice, and he was further able to prevent or cure it by administering an extract of rice polishings. The discovery that the disease could be thus produced and cured experimentally greatly assisted its study; just as the later observation of Holst and Fröhlich that the guinea pig rapidly displays the symptoms of scurvy when placed upon scorbutic diets, while promptly cured by antiscorbutics, made easy the experimental study of the latter disease and provided a ready biological test for the presence and relative amounts of the curative agent in various foods.

The explanation first offered by Eijkman for the production of beriberi during the consumption of polished rice was to the effect that the condition is a state of intoxication brought about by the consumption of excessive quantities of starch, and that in the so-called "silver skin" which is removed by polishing, though not in the bulk of the grain, there is a substance which counteracts the toxic products of the disturbed metabolism. This hypothesis was far-fetched and inhibitory, but the conception of disease as the direct result of a specific deficiency in food was foreign to the thought of

the time. Later, however, partly owing to the work of others and partly to extended experiments of his own, Eijkman came to the definite conclusion that there is present in rice polishings an individual substance differing from the then known food constituents, but essential to normal nutrition, though required in very small amount. Even before Eijkman himself had come to this final conclusion, the work of others had made it probable, and by 1910 the significant facts had become fully established. Among those whose work contributed to their establishment must be mentioned: Grijns, a countryman of Eijkman; Vedder and Chamberlain, of the American Medical Service; and the British investigators Fraser and Stanton, whose investigations were carried out in the Malay States. All of these helped to prove that the preventative of beriberi is a definite chemical substance, and the last mentioned in particular took pioneer steps which were ultimately to lead later workers to a successful isolation of that substance.

Those who worked on beriberi during these years thought and wrote as pathologists, with their attention primarily directed to the causation and cure of a particular disease. Though doubtless the suggestion for an extension of the kind of knowledge gained was ready to hand, as a matter of fact their writings at first contained no reference to the possibility that substances with the properties we now attribute to vitamins might function widely and prove to be necessary for the support of such fundamental physiological processes as growth itself.

This more general and more physiological conception of the functions of vitamins arose directly from the results of feeding animals on experimental diets. If the assumption were right that proteins, fat, and carbohydrates, together with essential minerals, are the sole nutritional necessities, then these materials should support all the functions of the body when each of them is supplied in a pure form, no less adequately than when, in natural foods, they are consumed in association with small amounts of many other substances. The nutritional value of such purified materials supplied in artificial dietaries was at one time the subject of many experiments. The results of these were uncertain and contradictory, owing to the fact that purification was often not complete. It was not then realized that substances present in extremely small amount may profoundly affect the value of a diet. It is this circumstance that our present knowledge of vitamins has made so clear. In 1906–7 the writer engaged in feeding rats upon highly purified materials of the above kind, and found them wholly unable to support health or normal growth, though certain additions, very minute in amount, greatly increased their nutritional adequacy. It happened that yeast ex-

tracts were among the addenda which were successful in this respect, but only, as is clear today, because the fat employed in these experiments was filtered butter fat. We know now that butter itself contains certain of the essential vitamins, while yeast supplied the others. These experiments confirmed a personal belief in the importance for nutrition of minor constituents in natural foods, and public expression was given to this belief; but the experimental results were not then published.

In the autumn of 1911 the results of later experiments were communicated to the Biochemical Society, and these were published in the following year in a paper which made a general claim for the "importance of accessory factors in normal dietaries." Funk at about the same time impressively summarized the then available knowledge concerning deficiency diseases, and proposed the name "vitamine" for the substance of which a lack might in each case be presumed to produce the pathological condition. On chemical grounds J. C. Drummond suggested that the final "e" in Funk's proposed name should be omitted, and this has become customary. By 1912, then, there was fully adequate evidence for the wide importance of vitamins, and from that time progress in their study has been continuous.

Immediately before the war and until near its end, American investigators were the chief contributors to this progress. T. B. Osborne and L. B. Mendel at Yale and E. V. McCollum at Wisconsin (afterward at Johns Hopkins University) were separately engaged upon nutritional experiments with artificial dietaries. For a little while after the present writer's publication in 1912, these workers were not fully convinced of the necessity for a vitamin supply. Osborne and Mendel believed for some time that they had succeeded in maintaining rats upon purified diets. Soon afterward conviction came, and important contributions to the subject were made at both centers. In particular, American studies produced at this time proof that vitamins existed in natural foods in different associations, and led to a distinction between "fat soluble" and "water soluble" individuals; a distinction which, though in itself not of fundamental importance, greatly helped later developments in the subject, many of which have been due to workers in America.

During the later stages of the war, when many nutritional problems had to be faced, intensive studies began at the Lister Institute in London. These comprised pioneer work by A. Harden and S. S. Zilva, and the important experiments of Harriette Chick and her colleagues, which have continued to the present day. At this time, University College, London, became also a center of activity owing to the work and influence of J. C. Drummond, while the classical

experiments of E. Mellanby on the production of rickets were already in progress. A few years later, interest in the subject penetrated into every European country, and research became everywhere very active. Recently, publications dealing with vitamins have reached a total of a thousand in a single year.

Today we have knowledge of some eight or nine vitamins, each proved to have its own specific influence in maintaining the normal course of events in the living body, and each exercising its functions when in exceedingly small concentrations. Happily the actual chemical constitution of some of them is now known.

It is, of course, impossible in a brief review to recount all the stages of discovery in the case of each of these substances. The existence of individual vitamins, each with its special influence in the body, has in the majority of cases been revealed by the experimental feeding of animals on the following general lines. Natural products or preparations—crude when experiments began—from natural sources, animal or vegetable, when simultaneously added in characteristically small amounts to a vitamin-free dietary, were found to render it capable of supporting normal nutrition. The tendency at first was to assume that each effective addendum contained one active ingredient. The next step in progress, however, involved the fractionation of each crude preparation, and this in many cases revealed the presence of more than one vitamin, with obviously distinct functions, each calling therefore for separate endeavors toward its isolation and purification. It may be mentioned in illustration that yeast, which, because it represents a concentrated mass of living cells capable of active growth, and at the same time is available in large amounts, was early and justifiably looked to as a probable source of vitamins, has yielded some of them in a complex which even today has perhaps not been fully analyzed.

The position of knowledge at the present moment will be made sufficiently clear if the most salient characteristics of each recognized vitamin are very briefly reviewed. Unfortunately, it is impossible at the same time to give credit to the many who have shared in the heavy labors involved in the remarkable recent advances in the subject.

Vitamin A.—This vitamin is found in association with animal fats and exists in specially high concentration in the livers of fishes. It was discovered and studied in cod-liver oil and at first was not distinguished from vitamin D, but by 1922 it had become clear that there were two "fat soluble" vitamins with functions entirely distinct.

Vitamin A exerts an important influence in the body. In its absence young animals fail to grow. Lack of a proper supply leads to

degenerative changes in the epithelial cells which line the outer surfaces of the body, and among the characteristic symptoms which follow upon such a lack is a pathological condition of the eyes known as xerophthalmia. As an independent phenomenon, night blindness may occur. Very noteworthy is the evidence which shows that an adequate supply of this vitamin protects against certain types of infection. One of the most interesting advances in our knowledge of vitamins is the recent proof that vitamin A is closely related chemically to the carotenes, a group of yellow pigments widely distributed in plant tissues, and the further proof that carotenes, when they are consumed in green vegetables, are converted in the liver into the vitamin itself. These discoveries have thus shown that vegetable foods are an effective source of the vitamin, and they have also greatly helped in leading to our present knowledge of its actual chemical nature. It has been obtained pure in the form of an oil, and chemical studies have revealed its essential molecular structure.

Vitamin B_1.—This is the vitamin of which a deficiency in the food supply leads as a final issue to the disease beriberi. It exerts a general influence in the body, and would seem to be essential to the normal progress of carbohydrate metabolism, but a specialized aspect of its functions is the maintenance of a normal equilibrium in the nervous tissues. It is widely distributed in natural foods, but in concentrations which vary greatly. We have seen that the circumstance of its presence in the cortical parts of grains and absence from the endosperm led, through the work of Eijkman and his followers, to one of the earliest suggestions for the existence of vitamins. It is relatively abundant in yeast, and this has been the material chiefly used as a source of it for experimental work. Much effort in Great Britain, in particular by R. Peters, has been spent in the effort to obtain it in a pure state, an end which seems now to have been reached. Its actual molecular structure is not yet known, but its empirical formula is probably $C_{12}H_{16}N_4OS$. Alone among the known vitamins it contains sulphur in its molecule.

Vitamin B_2.—When yeast extracts were first employed as addenda to deficient diets, their most notable effect, apart from the promotion of growth, seemed to be the prevention of nervous lesions. They were supposed to supply an "antineuritic" vitamin alone. This is now B_1. Further studies of such extracts showed, however, that they certainly contain at least one other vitamin more stable toward heat than B_1, and clearly showing quite different properties. In its absence serious skin lesions develop, resembling in animals those seen in the human disease pellagra. There is now indeed little doubt that a prominent factor in the causation of this disease is a lack of this vitamin in the food. It has been labeled B_2. Quite

recently, however, a further complication has come to light in this connection. Preparations of "B_2" as hitherto employed would seem to contain two active factors, one promoting growth without being concerned with skin conditions, and a second to which the "anti-pellagra" influence is due. The latter is now under intensive study, but its chemical nature is yet unknown. The former, like vitamin A, is related, as shown by the researches of R. Kuhn and P. Karrer, to a group of naturally occurring pigments, but in this case to the flavines. The vitamin is in fact identical with a flavine which is present in milk.

Vitamin C.—While the prevention and curative influence of foods containing this, the antiscorbutic vitamin, has been so long known, it remained for quite recent research to establish its existence as a definite chemical substance, to produce it pure, and to determine its exact chemical nature. It is present in most fresh foods but often only in very small amounts. It is present in greatest concentration in fruits and green vegetables, but in amounts varying greatly from species to species. Cereal foods contain none. It is characteristically less stable than the other known vitamins, being destroyed when foods are long kept, dried, or heated; the influence of oxygen being a potent factor in its destruction. This instability accounts for many chapters in the long history of scurvy and its incidence. Much labor has been spent during recent years in determining quantitatively its distribution in foods and in endeavor to isolate it. Success in the latter aim was reached by A. Szent-Györgyi 3 years ago. Its constitution has been fully worked out by W. N. Haworth and his colleagues, revealing the interesting fact that the physiologically potent substance is related to the simple carbohydrates, being a derivative of the hexose sugar gulose. The vitamin is now to be known as "ascorbic acid."

Vitamin D.—This, the antirachitic vitamin, is generally associated with vitamin A in animal fats, and, with the latter, is present in exceptionally large amount in fish liver oils. Studies in the etiology of rickets have proved that this disease can be prevented or cured, on one hand by an adequate supply of this vitamin in the food, and, on the other, by adequate exposure of the body to sunlight. A satisfactory explanation of this remarkable relation arrived with the proof that ultraviolet irradiation converts an inactive precursor into the vitamin itself, and that the former is present in the tissues. During the year 1929, owing in particular to the work of Rosenheim and Webster, and that of Hess and Windaus, it was made clear that the substance which on irradiation is activated is ergosterol, which in small amounts is present in most living tissues. As it is therefore present in many natural foods, the antirachitic value of these is

increased by exposure to rays of suitable wave length. A preparation of the vitamin made by the irradiation of ergosterol in vitro is known as "calciferol." Its potency is remarkable; one ten-thousandth of a milligram a day added to a rickets-producing diet will in a rat entirely prevent the appearance of the disorder. In the case of a child the effective daily dose is a very small fraction of a grain. The rigorous proof that lack of a fat-soluble vitamin is responsible for the induction of rickets was furnished by the classical experiments of E. Mellanby begun 20 years ago. More recently the importance of vitamin D in the processes of normal dentition has been shown by May Mellanby.

Vitamin E.—In 1922 it was first shown by H. M. Evans and K. S. Bishop that a vitamin, distinct from others then known, is essential for successful reproduction. It has been termed the anti-sterility vitamin, but this term implies functions more specific than those which are actual. Deprivation of vitamin A, for example, will ultimately lead to failure in reproduction. Nevertheless, the influence of vitamin E (now so-called) is exerted on specific lines. In its absence there is degeneration of the testes in the male and a failure of the placental functions in the female. The richest sources of this vitamin so far discovered are certain green vegetables and wheat embryos. It is, however, widely distributed in foodstuffs, and as it is active in very small amounts, the possibility of any lack of it can seldom arise. Its constitution is unknown.

These very brief descriptions of the known vitamins leave out, of course, a multiplicity of facts which have been discovered concerning each of them, and omit reference to the work of very many investigators. They may serve, however, to indicate the lines on which vitamin research has hitherto progressed.

Characteristic of each vitamin is the very small amount in which it exercises its physiological functions, and the circumstance that all are present in very low concentrations in the materials from which they have to be separated has greatly added to the difficulties of their study. It will be admitted, however, that we have now a sound body of knowledge concerning them, establishing their nutritional importance and throwing no little light on their nature. Research in the field is now receiving much help on its constitutional side from modern physical methods, and on its biological side from increasing interest on the part of a large number of clinicians. Vitamin therapy is now joining hands with endocrine therapy, and the League of Nations Permanent Commission on Biological Standards has recognized its growing importance by accepting standards for measures of vitamin activity and defining units in terms of such standards.

Some, at least, of the conditions which are now grouped as deficiency diseases are of world-wide importance, and though the clear-cut symptoms which the experimentalist can observe in animals under strictly controlled conditions are often obscured by intercurrent infections or other complications in clinical cases, yet once a food deficiency has been recognized as an essential link in the chain of causation the method of cure becomes in every case as certain as it is logical. On the other hand, once the hygienist has become convinced that this or that disease is really due to faults in the diet of communities its prevention, with or without administrative action, should be easy to secure. Although a defect in the supply of a vitamin, if serious and continued, may result in actual disease, it is in Great Britain more important to realize that a suboptional supply of any essential food constituent cannot fail to induce subnormal health which, especially when induced in childhood, may leave permanent disability.

Apart from its own inherent importance, the revelation of the significance of vitamins can fairly be said to have directed closer attention to the nutritional importance of other minor constituents of natural foods. The specific needs of the body are proving to be numerous, and lack of materials called for in very small amounts are proving to be just as important to final issues in nutrition as are those required in much larger amounts. This applies to the mineral as well as to the organic constituents of food, and ill-assorted diets may be deficient in the former no less than in the latter.

For the progress of scientific knowledge concerning these needs, each separate factor has called, and continues to call, for separate and intensive study; but the demands of right nutrition need to be viewed as a whole. We need to know what should be the ideal balance among the many essentials, and how best to secure that it shall be approached in the food supply of all classes of the community. Short of this, we have today sufficient knowledge to be sure that malnutrition in its subtler aspects often accounts for disabilities which have hitherto been ascribed to constitutional defects or to other circumstances. With present knowledge, moreover, it should be easy, economic questions apart, to prevent such malnutrition everywhere. There is almost sufficiency in the statement that certain foods often held to be luxuries have to be recognized as necessities for all. Recognition of this bears upon all the problems of a national food supply; upon production, preservation, transport, and distribution.

It is interesting to remember that the effective development of the recent knowledge concerning the more subtle aspects of nutrition has been almost coterminous with the reign of King George.

THE SALINITY OF IRRIGATION WATER

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[With 3 plates]

INTRODUCTION

In the course of its development our irrigation agriculture has, in some areas, utilized all of the available supplies of surface water. Further progress calls for the use of underground water obtained by pumping. In some situations, as in southern California and in Utah, it has been found that some of the underground water is unsuited for irrigation use because of the nature or quantity of its dissolved salts. Furthermore, it has been found that some of the supplies of surface water, such as the Rio Grande and the Colorado River, also contain dissolved salts in quantities or of kinds that cause trouble after some years of use on the same land.

These experiences have appeared to warrant investigation of the subject of the salinity of irrigation water in relation to the possibilities and limitations of the further and more efficient utilization of the water resources of our arid regions and also in relation to the sustained productivity of our irrigated lands. The history of irrigation in other lands has shown that in some places irrigation agriculture has been carried on successfully for long periods, as in Egypt, while in other places, as in Mesopotamia, it has failed to survive. The direct causes of failure have been various. Salinity of the water may have been only one of several reasons. But it is fairly certain that in every one of the long-continued irrigated areas the quality of the water has been excellent.

THE SALINITY OF SOILS

The phenomenon of soil salinity is one that is usually associated with regions having an arid climate. The obvious reason for this is that the water-soluble salts resulting from the weathering of rock material into soil are leached away by the rains in a humid climate, but remain in the soil under arid conditions. There are exceptions

in both cases. There are limited areas of saline soil to be found in regions where the climate is unquestionably humid and where soil leaching is the normal condition. These limited saline areas occur where local surface drainage is inadequate and where the texture of the soil is such that no downward percolation of water occurs. Long-continued evaporation of water from such an area results in the gradual accumulation of soluble salts in the soil. On the other hand, there are in arid regions very extensive areas of soil which are not saline. This may be due in part to the fact that the rock material from which the soil was formed contained little, if any, water-soluble material and in part to conditions of soil texture or of surface topography that favor soil leaching even by limited rainfall.

In general, saline soils occur in topographic depressions where the drainage from adjacent higher land is retained and evaporated. There are, however, some saline soils of rugged topography, such as the so-called "bad-land" formations, that constitute the remnants of sedimentary deposition in saline or brackish waters.

Within the boundaries of the United States the existence of naturally saline soils is not an important agricultural problem. They occur only to a limited extent in regions where the rainfall is adequate for crop production without irrigation, and in the drier parts of the country the extent of the nonsaline arable soil is generally much in excess of the available supplies of irrigation water. This is not to say that the pioneers of our arid regions have not attempted to reclaim and to utilize areas of saline soils. Many such attempts have been made, a few with some measure of success. With us, however, soil salinity as a major agricultural problem occurs not as a consequence of natural preexisting conditions, but rather as the result of the ill-advised use of saline irrigation water on soils that were originally nonsaline and potentially productive. It is because the problem of salinity in relation to crop production is almost wholly consequent on the accumulation in the soil of dissolved salts transported by irrigation water that the subject is discussed from this standpoint.

THE SOURCES OF SALINITY

The water-soluble salts that occur in our agricultural lands are not, in any large part, the result of local soil weathering. They are chiefly the result of water transport, either natural or artificial. The original water is, of course, pure because it comes from rain or melted snow, but it becomes contaminated with dissolved salts as it passes over or through the soil. Most of the salt found dissolved in natural water originates from the decomposition of rock material, but there is a small part, at least, that comes from the interior of the earth. Such salt constituents as carbon dioxide, chlorine,

and boron, to name only a few, occur in gaseous form with hot water vapor deep in the earth's crust. These gases reach the surface through rock faults or fumaroles. In some situations these gases may escape into the atmosphere to return to the earth dissolved in rain water, but more often they encounter and are dissolved in superficial percolating water and appear at the surface as springs, often warm or even very hot.

Many of the so-called "mineral springs" originate in this way, and although it is probable that only a small proportion of the total quantity of salt that is carried by irrigation water comes directly from magmatic sources, these sources are important in some instances. The rains that fall in the occasional torrential storms of desert regions contribute a part of the dissolved salts to the streams that drain those regions and that are most extensively used for irrigation. Another source of salts exists in the irrigated lands that lie adjacent to these streams. The water that is diverted from streams or drawn up by pumps from the underground supplies that are replenished from streams contains dissolved salts. A large part of the water used in irrigation is absorbed and transpired by crop plants or evaporates directly from the soil. Of the dissolved salt it contains, very little is absorbed by the crop plants, and none is dissipated by evaporation. Consequently, it accumulates in the soil to which the water is applied.

The salts thus transported to and left in the soil by irrigation water are of many different kinds. Some of them, such as calcium carbonate and calcium sulphate, have very low limits of solubility, and as the water is absorbed by plants or evaporated from the soil these salts are precipitated from solution so that they become inactive and not injurious to plants. Many of the other salts have higher limits of solubility and remain dissolved in the soil solution until concentrations are reached that make this solution unsuited for use by the roots of crop plants. In order to avoid crop injury from this cause it is necessary, in many situations, to provide artificial drainage for irrigated land to remove the salts of high solubility. The drainage from such land, whether natural or artificial, usually finds its way or is discharged into the same stream from which the irrigation water is diverted. The total quantity of salt returned to the stream by drainage from irrigated land may be less than the quantity brought in by the irrigation water, but, because the volume of drainage or return flow is less, the concentration of the dissolved salts is higher in the stream below the diversion point than above it. An example to illustrate this effect of diversion and drainage on the salt content of a stream may be taken from the Rio Grande in New Mexico and Texas. Water is diverted from this stream at Leasburg, N. Mex. Between that point and Fort Quitman, Tex., there

is an irrigated area of some 150,000 acres contiguous to the stream. The drainage from this irrigated land returns to the stream above Fort Quitman. During the calendar year 1933 the volume of the discharge of the river at Leasburg, including the water diverted for irrigation, was 824,000 acre-feet containing 651,000 tons of dissolved salts or 0.79 ton per acre-foot. During the same year the volume of water passing Fort Quitman, including returned drainage water, was 214,000 acre-feet containing 582,000 tons of dissolved salts or 2.72 tons per acre-foot. Consequently, the effect of irrigation and drainage on the salinity of the stream in this section of its course was to increase its concentration from 0.79 to 2.72 tons of dissolved salt per acre-foot of water.

It is obvious that the net effect of the irrigation of this land is to increase the salt concentration, if not the total salt burden, of the stream that serves it. Thus it seems proper to include irrigated land as one of the sources of the salinity found in irrigation water. The principal sources, then, are: (1) The soluble products of the formation of soil from rock weathering; (2) gases of magmatic origin from deep in the earth's crust; (3) the erosion by rainfall of older sedimentary deposits and the solution of salts deposited at the time of their formation; and (4) the drainage of irrigated land.

IRRIGATION WATER AND THE SOIL SOLUTION

The water required by crop plants in the process of growth is absorbed by their roots from the solution suspended in the soil within the zone occupied by the roots. This root zone varies in depth with different crops and with different soil conditions. In general it ranges from 2 to 6 feet or more in depth. The capacity of the soil of the root zone to hold water against the force of gravity is limited to what is known as its field capacity, and, on the other hand, the crop plant is not able to utilize all of the water contained in the root zone because of the tenacity with which the soil holds a portion of that water. The quantity of water held in the root zone at any one time and available for use by crop plants must lie between these limits. The relationship between this quantity of water and the current daily water requirements of crop plants is such that during the active growing season the supply of water must be replenished from time to time. In an arid climate this is done by irrigation, and experience has shown that during the season of active growth the periods between irrigations should rarely exceed 40 days, and with some crops and some soil conditions the period should not exceed 14 days.

In dealing with the subject of salinity it must be understood that when the water supply of the root zone of the soil, known as the soil solution, is replenished by irrigation, there is added to that solution

whatever quantity of dissolved salt is contained in the irrigation water. Insofar as the water of the soil solution is dissipated by direct evaporation from the soil, the remaining solution becomes more concentrated because the dissolved salts do not evaporate. The effect on the soil solution of the absorption of water from it by crop plants is almost the same as the effect of evaporation, because plants absorb a much larger proportion of water than of the dissolved salts when the concentration of the solution is above a very low level. Thus when saline irrigation water is used the trend of events is in the direction of an increasing concentration of salinity in the soil solution.

This trend toward increasing concentration is limited by two processes. One of these operates through the precipitation from the solution of the salts of low solubility, which occurs with such salts as calcium carbonate and calcium sulphate at concentration levels well below the limits of tolerance for most crop plants. In other words, the addition of these salts to the soil solution might continue indefinitely and at any rate without impairing the productivity of the soil because they would precipitate from the saturated solution and become a part of the solid phase of the soil. The other limiting process operates through the percolation downward of the soil solution with its dissolved salts to levels below the root zone. This process occurs naturally if and when the downward path is open and when the quantity of irrigation water applied is greater than the water-holding capacity of the soil of the root zone. In some situations the downward path is not open because of a subsurface layer of rock or impermeable clay. In other areas it is impeded by a water-saturated zone of subsoil known as a "water table."

In order to prevent the excessive accumulation of soluble salts in the root zone of irrigated soil it is not enough that the way of escape below shall be unimpeded. There must be some displacement of the solution, or leaching, through the application, at least occasionally, of more than enough water to replenish the root zone to its capacity. In many places, particularly along the Pacific coast, the necessary leaching occurs as a result of winter rains that come during the dormant season. When such rains are inadequate to cause some leaching it becomes necessary to do it with irrigation water.

As a result of the processes of concentration that occur in the soil solution of an irrigated field the soil solution is always more saline than the irrigation water. Where subsoil drainage is free and water is used copiously, the concentration of the soil solution may be only twice that of the irrigation water. If the subsoil drainage is poor or if irrigation water is used too sparingly, the difference will be much greater. In general, it is found that the concentration of total dissolved salts

in the soil solution of an irrigated field is four to eight times that of the water with which the field is irrigated. Such differences do not occur with respect to all the salt constituents. Those constituents that form salts of low solubility cannot exceed that limit. Furthermore, there may occur in the soil reactions of base exchange by which the proportions of some of the constituents may be modified. The point here to be emphasized is that in considering the relationship between the salinity of irrigation water and the salinity tolerance of crop plants it should be kept in mind that the plant must obtain its water supply from the soil solution, which may be very much more saline than the irrigation water. Furthermore, any standards to be used for the quality of irrigation water must be influenced by consideration of the regimen of irrigation and the conditions of soil and climate involved.

THE CONSTITUENTS OF SALINITY

In order to understand the nature and apparent complexity of the problem of salinity in irrigation water it is necessary to recognize as a fact that this salinity includes not only a number of different salts, but what is even more important, that each of these salts is composed of at least two constituents. Our best information is that the reactions and effects that occur in the soil solution or subsequently in the plant are produced by the salt constituents or ions rather than by the salts as such. In water solutions of common salts or electrolytes it is believed that the salt constituents exist largely as independent dissociated ions. Furthermore, the analytical methods, by which their concentrations in water solutions are measured, are based on determinations of the individual constituents rather than of the salts in their combined form.

Natural waters, such as are used for irrigation, contain in solution a very large number of constituents. Rarely if ever does an analyst attempt to determine all of them. Probably most of the analyses of irrigation water are limited to the determination of the anions: Carbonate (CO_3), bicarbonate (HCO_3), sulphate (SO_4), chloride (Cl), and nitrate (NO_3), and in the cation group the determinations seldom include more than four: Calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). In addition in some cases it is necessary or desirable to determine the concentration of certain elements such as iron (Fe), aluminum (Al), silicon (Si, or as silica, SiO_2), boron (B), fluorine (Fl), and selenium (Se). These last named constituents usually, though not always, occur in small quantities, and although they may exist in the solution in ionic combinations, the nature of these combinations is not well enough known to warrant their identification except as elements.

It is characteristic of these water solutions of electrolytes that the total number of ions or combining units of each group must be the same, that the sum of the cations must equal the sum of the anions. This equality of numbers may be achieved by dissociation of the water molecule into its potential constituents, hydrogen (H) and hydroxyl (OH). The extent of this dissociation and the nature of the resulting equilibrium may be measured by the so-called "hydrogen ion concentration (pH)." Thus acid waters are those in which hydrogen ions must be included with the cations to achieve equality of number, whereas in alkaline waters the requisite number is contributed by hydroxyl ions.

Two methods are used to indicate the quantities of dissolved salts in a solution. The several ionic constituents of the dissolved salts have different gravimetric values. For example, if we assume that a combining unit of hydrogen has a gravimetric value of 1, then an equivalent combining unit of chlorine has a gravimetric value of 35.5, while that of the sulphate ion (SO_4) is 48, and that of the nitrate ion (NO_3) is 62. This relationship between numbers and weight is involved in the two methods that are in current use for reporting the concentration of the ionic constituents of the salinity of irrigation water. By one of these methods the gravimetric values are reported, usually as milligrams per liter, which is equivalent to parts per million. By the other method the values reported as milligram equivalents per liter imply the relative numbers of each ionic constituent. The value reported by either method may be readily converted into the other scale by the use of appropriate factors for each ion.

THE EFFECTS OF SALINITY

The dissolved salt constituents that occur in the soil solution as the result of the use of saline irrigation water produce effects that fall into two categories. One includes the effects on crop plants and the other includes effects on the physical condition of the soil. In both cases the reactions appear to be related to the concentrations of the individual salt constituents, rather than to the concentration of the combined salts. The effects of these salinity constituents on the physiological process of plant growth do not operate independently of each other; but for the most part the interrelationships appear to exist between the constituents of a group rather than between the two constituents of any given salt. For example, the effect of magnesium may be influenced by calcium, that of calcium by sodium, or the injury caused by boron may be influenced by the concentration of nitrate or the injury of selenium by the concentration of sulphate. Thus the influence of one cation may be modified by the concentration

of another cation, but there is little evidence to support the view that the physiological effect of an anion such as chloride is any different whether its salt-forming companion is sodium or calcium.

Some of the constituents of salinity are essential to plant nutrition. This is certainly true of such cations as calcium, magnesium, and potassium, and of such anions as sulphate and nitrate, to enumerate only a few. However, the concentration levels at which several of these constituents commonly occur in saline irrigation water is much above the optimum for plant nutrition. It is probably true that in respect to many of the ions or elements that occur in solution in natural waters or in the soil solution there are concentration levels that are below the optimum for plant nutrition as well as higher concentration levels at which the same ions or elements become toxic. This is not known to be true of all of these constituents. Chloride, for example, is probably not essential, at least to many plants, and there is some reason for believing that it may cause some depression of growth when it occurs in concentrations that are much lower than those that are associated with definite symptoms of malnutrition or that kill the plant.

There are very pronounced differences in the toxicity of the different solution constituents. Boron, for example, may cause serious injury when its concentration in irrigation water is less than 1 part per million or when in the soil solution its proportion is not more than 3 or 4 parts per million. With chloride, as another example, concentrations up to 150 to 200 parts per million in irrigation water may not cause obvious symptoms of injury even though the soil solution resulting from the use of such water may contain 3 or 4 times that concentration.

There are also very great differences among crop plants in respect to their limits of tolerance for any one constituent of the soil solution or for all of those constituents taken together. This aspect of the subject is discussed in some detail in a later paragraph.

In the case of plants it is probably true that nearly every one of the dissolved constituents of the soil solution has some effect, for good or ill, on the plant. This is apparently not true of the relationship between these solutes and the physical condition of the soil. Our concern about the soil is due to the fact that its function as a suitable reservoir for the soil solution is profoundly influenced by its physical condition in relation to its permeability, and that this in turn is influenced by the nature of the cations introduced into the soil solution by the irrigation water. These cations participate in reactions of exchange between the solution and the soil. So far as we now know, such reactions do not occur between the soil and the dissolved anions. These anions, or some of them, may have some effect on the

physical condition of the soil, particularly when they occur in high concentrations in the soil solution, but that effect is probably not exerted through exchange reactions.

REACTIONS OF BASE EXCHANGE

It has long been known that one of the important phases of the so-called "alkali problem" in irrigated lands had to do with what was described as the puddling effect on the soil of "black alkali" or sodium carbonate. A puddled or impermeable soil is one that when wetted expands or becomes gelatinous so that water does not move through it readily. This condition occurs in irrigated soil on which soft water is used because saline soft waters contain sodium. It is only within the last decade or two that substantial progress has been made in understanding the nature and extent of the reactions by which such effects are produced. These are known as reactions of base exchange because they take place between the basic ions or cations of the solution and ions of the same group that are attached to some of the solid particles of the soil. The fact that exchange reactions take place between the soil and the salts of its solution was reported by an English chemist, J. Thomas Way, as early as 1852. But it was not until some 35 years later when the phenomenon of ionization was discovered that it became possible to understand how these reactions occur. The fruits of these discoveries have also been extensively utilized in industry in the process of artificial water softening by which the calcium and magnesium are removed from hard water intended for domestic use or for laundries.

The aspects of the subject of base exchange that are dominant in irrigated lands have to do with exchange reactions involving sodium and calcium. It is now known that deflocculated or impermeable soils contain appreciable quantities of sodium combined with the exchange complex. This sodium has been taken up by the soil from the soil solution in which sodium occurred, and such reactions take place regardless of the nature of the anion that was associated with sodium in the solution. In other words, sodium may be absorbed by the soil from solutions of sodium chloride or sodium sulphate as well as from solutions of sodium carbonate or "black alkali." It is implicit in the concept of the reactions of cationic exchange that for each ion absorbed from the solution by the soil another ion must pass into the solution from the soil; also that these reactions occur in the direction of attaining ionic equilibrium of concentration between the soil and its solution.

These facts concerning the reactions of base exchange afford a way of understanding the effects of the salinity of irrigation water

on the physical condition of the soil. When sodium is the chief constituent of irrigation water, and subsequently of the soil solution, the reactions between that solution and the soil are in the direction of increasing the quantity of sodium combined with the soil and of displacing an equivalent quantity of calcium, or other ions, from the soil to pass into solution. Reactions in that direction change the characteristics of the soil in the direction of deflocculation and impermeability. On the other hand, if a soil that is already deflocculated by sodium is irrigated with water in which calcium is the dominant ion, the exchange is in the direction of replacing the sodium combined with the soil by calcium from the solution with the result that the soil becomes flocculated and more permeable. One of the chief reasons for applying gypsum or calcium sulphate to irrigated soil is to improve its physical condition by this reaction. In a soil that was puddled or impermeable and has been flocculated by the application of gypsum, water may move freely either by gravity or by capillarity.

THE SYMPTOMS OF PLANT INJURY

The more obvious or striking effects of high concentrations of salinity in the soil solution are to be seen in irrigated fields containing areas of bare soil or of salt-tolerant weeds. In these areas the growth of crop plants may be completely inhibited by excessive salt concentrations. Surrounding these areas there is usually a zone in which there are a few crop plants of subnormal size, while normal and vigorous plants occur outside of the intermediate zone. This is the characteristic manifestation of salt injury to field crops. One seldom sees a whole field in which the intensity of injury is uniform. This is because of the natural and universal variability of soil conditions. Some species of crop plants exhibit characteristic symptoms of injury in their leaves or stems that may be identified as the result of high concentrations of one or another salt constituent. In general, however, concentrations of salinity insufficient to kill plants merely retard growth processes and reduce the size or yield of crop plants.

The absence of characteristic symptoms of salt injury in many crop plants has made it difficult to distinguish that cause in its early stages from other causes of poor growth or low yields. Such other causes as adverse climatic condition, low fertility, or the depredations of insect pests or plant diseases are often ascribed as the reason for unsatisfactory crop growth whereas the dominant cause may be excessive salinity in the soil solution. The fact that the real cause of trouble may be due to some one of the several constituents of that salinity or to adverse soil conditions caused by one constituent in-

creases the difficulty of correct diagnosis. Impaired crop growth or reduced yield may occur where the concentration of total salinity is low, but where the trouble is due to the excessive concentration, either absolute or relative, of some one constituent of that salinity. The injurious effects of boron and of high ratios of sodium occurring in solutions of low total salinity may be cited as examples.

There are some crop plants that do exhibit recognizable symptoms of injury from one or another of the salt constituents. These symptoms may be associated with impaired growth rate or they may occur, in mild form, without measurable evidence of general growth depression. As an example, it has been found that when the boron content of the soil solution is approximately 3 parts per million the leaves of lemon trees show a characteristic pattern of yellow color in the tissue between the veins, with some marginal necrosis. This symptom appears even when the degree of injury is so slight that growth and fruiting are not measurably depressed. Other and no less definite symptoms of boron injury are known in other plants, and there are still other examples of abnormalities of color or form in plants that are associated with nutritional derangements consequent upon excessive or abnormal salinity conditions in the soil solution. With some few exceptions, however, the adverse effects of salinity constituents in the range of toxic concentrations are manifested only by the depression of the rate of growth.

RANGES OF PLANT TOLERANCE

In attempting to set up standards of reference by which to translate the data of water analysis into terms of the tolerance limits of crop plants one encounters difficulties of several kinds. It has been pointed out in an earlier paragraph that the plant has to deal with the soil solution, and that there is no constant relationship between the concentration of the irrigation water and of the soil solution. Because of the practical difficulty of extracting a sample of the solution from the soil in an undiluted condition we have fewer analyses of soil solutions than we have of irrigation waters. Thus the temptation is to compare the data of the analyses of the irrigation water with the behavior of the crops on which the water is used. Such a comparison is hazardous not only on account of the variable relationship between the irrigation water and the soil solution, but because the effect produced on any given plant species by any given concentration of a solution constituent may be profoundly influenced by the local climatic conditions. For example, a crop plant is more tolerant of salt in a humid coastal climate than in a dry interior climate.

It should also be recognized that there are great differences among the species of crop plants in respect to their tolerances to each of

the several constituents of salinity and that the group of species comprised in one system of agriculture may be wholly different from that of another system. These are examples of the variables that must be considered in determining the relationship between the quality of irrigation water on one side and of a profitable and enduring system of irrigation agriculture on the other. The demand for that comparison is frequent and insistent. It is not much less difficult to answer when its scope is limited to one constituent and one crop species. Not the least of the difficulty lies in our lack of precise knowledge in respect to the reaction of any given crop species to any given concentration of a solution constituent as influenced by climatic conditions, by stage of growth, or by the associated constituents.

Despite the recognized existence of all of these variables in the equation, it is possible to establish certain criteria by which to estimate the potential effect of the salinity of an irrigation supply on a given soil with a given climate and a given group of crop species. These criteria are of necessity based on field observation and on data of the quality of irrigation water. As an example of the sort of criteria that may be used, the following table is given. It represents the conclusions of a number of men who are well informed on conditions in one irrigated region and is used in connection with the appraisal of irrigated farms. In this table the boron constituent is emphasized because it is regarded locally as of critical importance.

TABLE 1.—*An example of the permissible limits adopted for a definite region of classes of irrigation water with respect to certain of its characteristics*

Classes of water	Concentration [1] total dissolved solids		Per-cent so-dium [2]	Boron, parts per million, crops group			Concentration in milligram equivalents	
	Conductance $K \times 10^5$ at 25° C.	Parts per million		A	B	C	Chlorides (Cl)	Sulphates (SO_4)
Class 1. Excellent, less than	25	175	20	0.33	0.67	1.0	4	4
Class 2. Good	25–75	175–525	20–40	0.33–0.67	0.67–1.33	1.0–2.0	4–7	4–7
Class 3. Permissible	75–200	525–1,400	40–60	0.67–1.00	1.33–2.00	2.0–3.0	7–12	7–12
Class 4. Doubtful	200–300	1,400–2,100	60–80	1.00–1.25	2.00–2.50	3.0–3.75	12–20	12–20
Class 5. Unsuitable, more than	300	2,100	80	1.25	2.50	3.75	20	20

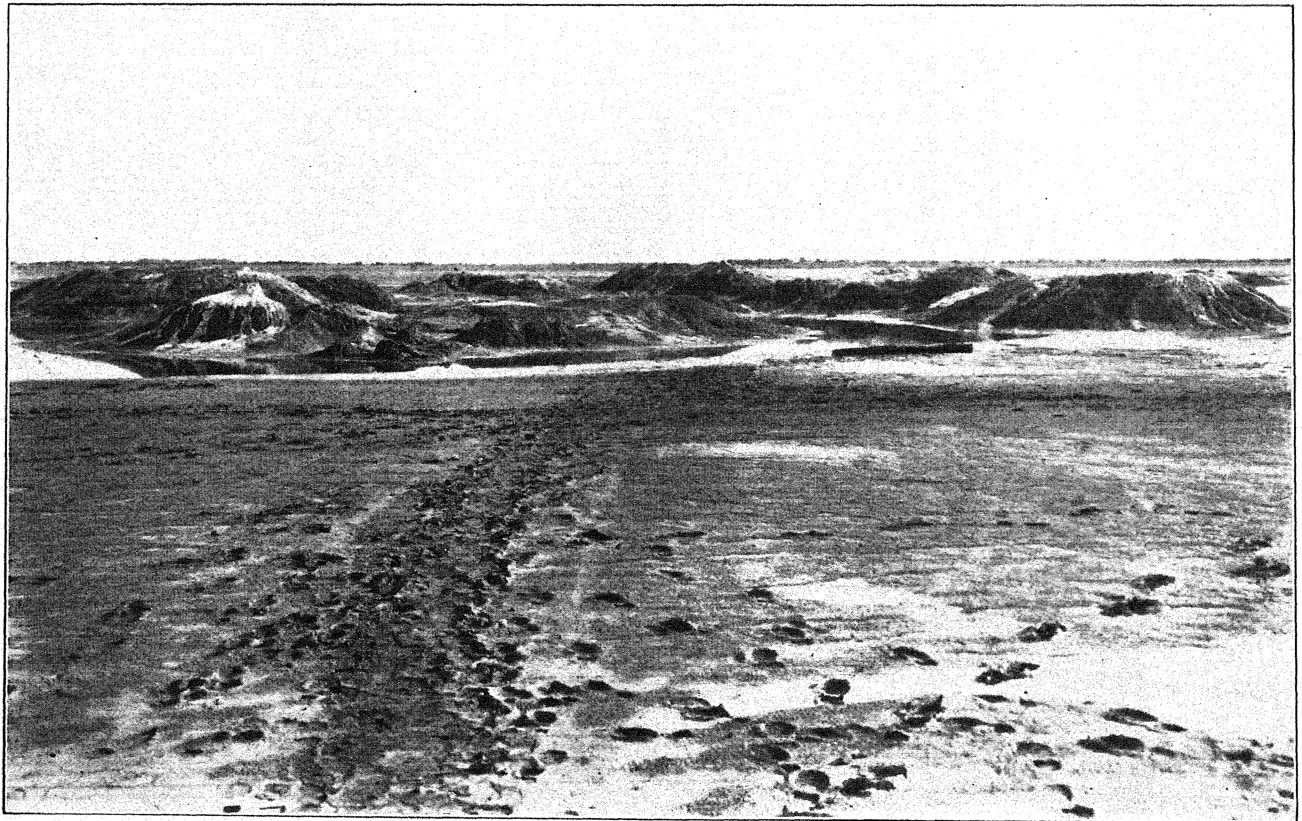
[1] The concentration of dissolved salts in water may be measured by either of two methods, that of electrical conductance and that of evaporating the water and weighing the residue.

[2] This percentage represents the proportion of sodium to the total cations and is computed from the data of analysis, reported as milligram equivalents, by dividing the sum of the values for sodium and potassium by the sum of the values for all the cations

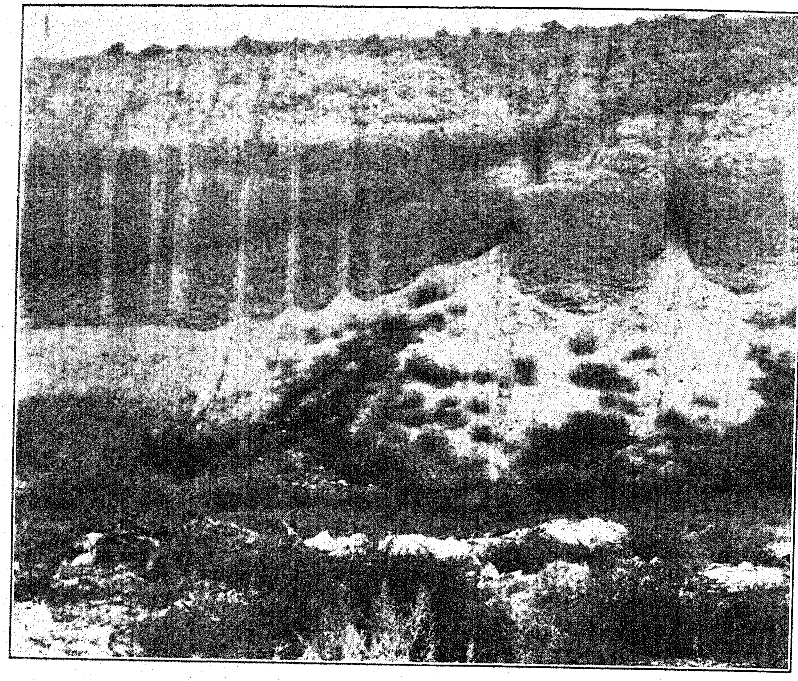
In the application of the class limits given in the table consideration is given to (1) the crop group, (2) soil type, (3) climatic conditions, (4) relative quantity of irrigation water to rainfall. As applied specifically to the boron conditions the crop groupings are:

A, fruit trees; B, vines and cereals; C vegetables. The concentration of total salinity is considered in connection with boron and sodium percentage. If all three rate class 3 or higher, the water is unsuitable. In general if the water rates class 4 for any two or more characteristics, it is classed as unsuitable.

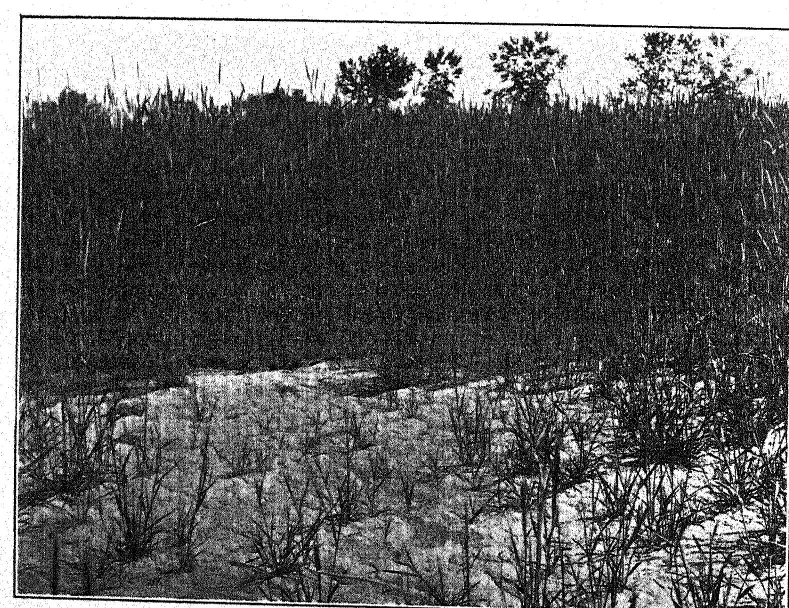
It should be understood that class limits or standards given in the table are intended for use in a particular area and should not be taken as applicable everywhere. It should be clear that it is not practicable to use one set of standards for all irrigation waters or for all sorts of crops, or for all sorts of soil and climatic conditions. Another error to be avoided is that of adopting a single criterion such as total salinity or the chloride content. Such simplification is not warranted by the facts in the case.



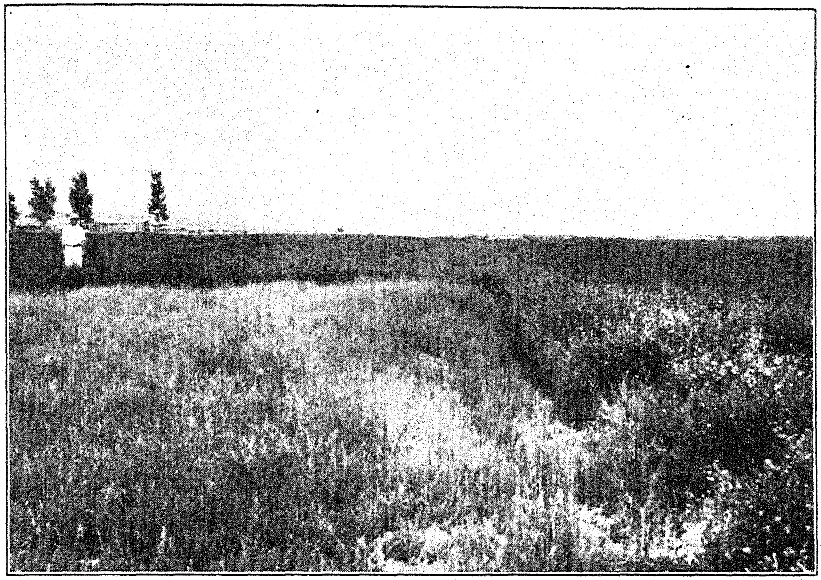
A group of fumaroles in the Colorado desert of Southern California through which salt constituents, boron, and chlorine, in gaseous form come to the surface from magmatic sources.



1. A deposit of saline sediments in western Colorado from which, by natural erosion, soluble salts are carried into the streams and ultimately to irrigated lands.



2. A saline spot in an irrigated field, showing sparse and restricted plant growth, surrounded by normal plants.



1. A saline spot in an irrigated alfalfa field, covered by salt-tolerant weeds.

2. View of an apple orchard in western Colorado in which dissolved salts brought in by the irrigation water have killed trees after they have made good growth and reached bearing age.

SELENIUM ABSORPTION BY PLANTS AND THEIR RESULTING TOXICITY TO ANIMALS

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(With 6 plates)

Unknown before 1817, selenium has been of interest primarily to physicists and inventors since 1873, when its remarkable photoelectric properties were discovered. Now it becomes of importance to the biologist and to the farmer as the cause of a serious disease of livestock known locally as "alkali disease",[1] although it may more properly be referred to as the selenium disease (Knight, 1935). About 20 years ago the plant physiologist added selenium to the list of elements known to be taken up from the earth by plants (Gassmann, 1917, 1919); and now the farmer of certain sections is faced with the fact that its presence in his land renders his crops unfit for food.

The selenium disease appears to be unique in that as far as is now known it is the only disease caused by vegetation made poisonous by an element absorbed from a virgin soil. It is fortunate that such soils are not more widely distributed.

Selenium occurs in many parts of the world combined with the heavy metals such as lead, silver, and copper, and in pyrites (Strock, 1935; Williams and Byers, 1934). It is commonly associated with sulphur of volcanic origin and is found in meteoric iron. Of the approximately 90 known elements it is about fiftieth in order of abundance, being just about as rare as silver (Noddack and Noddack, 1934). Traces of it are found in soils derived from shales over much of the United States (Byers, 1935); but only in certain restricted areas of the Middle West is it known to make vegetation toxic (Franke et al., 1934).

In France it has been found in the vegetation along canals from mineral springs containing selenium (Taboury, 1932). In Germany

[1] This name is a misnomer, the trouble being entirely different from that caused by an excess of certain salts in the water.

it has been found in plants growing in the vicinity of manufacturing establishments that produce seleniferous waste products, and in soils treated with fertilizers made from materials containing selenium as an impurity (Stoklasa, 1922). The increasing use of selenium-containing fungicides and insecticides in the United States raises a question as to the danger of still wider distribution, although it has not been shown that the form of selenium used in these materials is readily available to plants.

Before proceeding with the discussion of the absorption of selenium by plants, it may be of interest to relate how and why we know that the livestock disease of the Middle West is really selenium poisoning. The discovery of the cause of this obscure and baffling trouble, affecting the animals of certain restricted areas, constitutes one of the romantic episodes in the history of agriculture. By enlisting and combining the knowledge and experimental technique of the soil chemist and the plant and animal physiologists, the problem has progressed from the discovery of the cause to suggestions for control in a surprisingly short time.

The existence of the disease has been known ever since the affected States were opened for settlement. The most conspicuous symptoms in horses, cattle, and pigs are the loss of hair, with deformity and eventual loss of the hoofs (pl. 1). Cattle lose the hair of the tail, and horses both mane and tail. The animals are often emaciated and lame, and those most severely affected die. Cattle and horses may die of thirst or starvation because of the difficulty of getting to food and water. If the toxic foodstuffs are removed from the diet, the animals improve to a considerable degree but never seem to recover entirely. In poultry the poison affects the eggs, most of which produce weak, abnormal chickens or fail to hatch (Franke et al., 1934).

The earliest reference to the disease seems to be a report of similar trouble affecting Army horses at Fort Randall, Territory of Nebraska (now in South Dakota), in 1856. Later, the early settlers in this region were confronted with the sickening and death of their animals. Pathetic letters are on file in the Department of Agriculture as far back as 1908, reporting the total loss in some instances of herds of valuable animals and appealing for information and assistance. The disease has thus interfered with the development of some sections of the country, and in others it still constitutes a serious handicap to farming. And all because too much selenium occurs in these parts of the earth's crust!

Some of the farmers themselves concluded that the trouble was due to something the plants absorbed from the soil. Scientists at the South Dakota Experiment Station then began experimenting and

definitely traced it to the grain in the diet of the affected animals (Evans, Bushey, and Kuhlman, 1925; Franke, 1934a). When a soil specialist (Rice) with other scientists of the Department of Agriculture made a survey of the region in 1931, he added the further bit of knowledge that the toxic vegetation occurred on soils derived from Pierre shales (Franke et al., 1934). This discovery was the clue that led the soil chemists to suspect selenium, an element that might reasonably be supposed to occur in the shales, and known to be poisonous to animals (Knight, 1935).

A search for selenium in the toxic soils, grain, and affected animals followed, and by careful painstaking analyses its presence in them in minute quantities was soon proved beyond a doubt (Robinson, 1933). At the same time it was shown that white rats with selenious acid added to their food developed symptoms of poisoning similar to those in rats fed the naturally toxic wheat (Munsell[2]). The gluten of the wheat was found to be the toxic fraction and to contain most of the selenium (Robinson, 1933; Franke, 1934b; Nelson[3]). Then wheat was grown in the greenhouse on soil to which a selenium salt (sodium selenate) had been added. The amount of this added salt was so small that the selenium constituted but one one-millionth of the weight of the soil. The plants grew normally, and the grain gave no sign of having anything the matter with it. But, amazingly enough, rats fed on it died while those fed on grain from the same soil without the selenium grew normally (Nelson, Hurd-Karrer, and Robinson, 1933). In more prolonged feeding tests the symptoms of the disease were produced by grain grown in quartz sand cultures to which sodium selenate was added (Munsell[2]). Finally, to clinch the evidence, inorganic selenium salts were fed to pigs (Schoening[4]). When their hair fell out and their hoofs developed abnormally just as they did in pigs that were fed the naturally toxic grain, it was concluded that the cause of the disease had been found.

It seems surprising that grain that looks normal in every respect should be so toxic. But this is consistent with reports from the toxic-soil areas that the plants there give no outward sign of abnormality. It is evident that animals are far more sensitive to selenium than are plants. Plants absorb relatively large amounts without visible injury and yet may kill animals. The reverse is true of boron. Plants may take up enough of this element to be fatally injured yet they are harmless to animals.

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[2] Report to be published by the Bureau of Home Economics, U. S. Department of Agriculture.

[3] Report to be published by the Bureau of Chemistry and Soils, U. S. Department of Agriculture. Referred to in the annual report of the Chief of the Bureau, 1935.

[4] Report to be published by the Bureau of Animal Industry, U. S. Department of Agriculture. Referred to in the annual report of the Chief of the Bureau, 1935.

In order to see how much selenium is necessary to visibly injure wheat plants I set up a series of experiments with increasing amounts of selenium in the form of sodium selenate added to pots of soil in the greenhouse. When the concentration reached 15 parts of selenium in a million of soil—i. e., 15 times the amount used to produce the grain that was toxic to rats—snow-white areas or streaks appeared on the leaves, like those on barley described by Turina (1922). With more selenium in the soil the entire leaf was sometimes snow-white. Such "chlorotic" plants look much like the decorative ribbon grass of the flower garden (pl. 2).

Under some conditions a still more striking sign of injury appeared, viz, the white areas became a beautiful deep rose or lavender-pink. This color is quite unlike the effect of any other known poison.

With some types of selenium salts, namely, the selenites, the roots become reddish, suggesting the presence of precipitated selenium. On examination with the microscope, the pink root tissues are seen to contain myriads of tiny red granules of selenium. This process of "reduction" of the colorless selenium salt to the colored element within the cell (Levine, 1915; Stoklasa, 1922; Turina, 1922) is a unique source of color in plants, the usual colors of leaves and flowers being due to organic pigments synthesized by the leaves. The red selenium color has been put to practical use in making red glass, such as that used for signal lights in railroad and traffic control, and the red enamels used in ceramics.

Chemical analyses show that selenium accumulates in plants in such quantities that its concentration becomes much higher than in the soil (table 1). In other words, the roots keep absorbing it and passing it on to the leaves, where it accumulates and makes the plants poisonous to animals. Up to a certain amount, about 300 parts per million, or 0.03 percent, of the dry weight, it does not affect the appearance of the wheat plant. But with larger amounts the characteristic "chlorosis" of the leaves appears. Wheat plants are almost killed by an accumulation of selenium equal to about one-tenth of 1 percent of the solid material of the leaves. Some other kinds of plants take up much more than this without showing injury, notably crops of the mustard family (table 2). Certain wild plants of the Wyoming seleniferous soils are reported to have a selenium content equal to nine-tenths of 1 percent of their dry weight (Byers). Naturally, such vegetation is extremely toxic to animals, and is now suspected to be the cause of a livestock disease of that area known as "blind staggers" (Beath, Draize, Eppson, et al., 1934; Beath, Draize, and Gilbert, 1934; Draize and Beath, 1935).

TABLE 1.—*Quantities of selenium taken up by wheat plants from sodium selenate added to soil. (Figures are parts per million of air-dry weights)*[1]

A. IN KEYPORT CLAY LOAM (VIRGINIA)

Selenium added to soil	Selenium found in plants	Condition of plants
10	380	Normal.
20	530	Stunted and chlorotic.
30	1,000	Severely stunted and chlorotic.
35	1,120	Nearly dead.

B. IN PIERRE CLAY (SOUTH DAKOTA)

Selenium added to soil	Selenium found in plants	Condition of plants
1	325	Normal.
3	330	Almost normal.
5	450	Stunted and chlorotic.
10	960	Severely stunted and chlorotic.
20	1,350	Nearly dead.

[1] Analyses by A. Van Kleeck under the direction of Dr. H. G. Byers, U. S. Bureau of Chemistry and Soils. The difference in absorption of selenium from the two kinds of soil is discussed in an earlier publi cation (Hurd-Karrer, 1935).

TABLE 2.—*Quantities of selenium (as parts per million on an air-dry basis) taken up by different kinds of annual crop plants from greenhouse plots treated with 5 parts of selenium (as sodium selenate) per million of soil.*[1] *None of the plants showed selenium injury*

Plant	Selenium	Plant	Selenium	Plant	Selenium
Mustard	1,240	Alfalfa	560	Proso millet	285
Broccoli	1,180	Pea	560	Corn	275
Sunflower	790	Oats	535	Crested wheatgrass	255
Flax	685	Wheat	470	Bromegrass	200
Sweetclover	645	Barley	450	Sorgo	130
German millet	590	Spinach	315		

[1] Analyses by A. Van Kleeck under the direction of Dr. H. G. Byers, U. S. Bureau of Chemistry and Soils.

Young wheat plants contain at least five times as much selenium per unit of dry matter as old ones, and leaves contain more than the stems and grain. Thus severely injured wheat plants grown with 30 parts per million selenium (as sodium selenate) added to the soil contained 1,120 parts per million when they were sampled at an early stage of development and but 220 parts per million at maturity. Similarly grown plants with 260 parts per million in their leaves at maturity had but 70 in the stems and 150 in the little grain that developed. Wheat grown in white sand cultures with nutrient solutions to which was added enough selenium (as sodium selenate) to produce a concentration of only 1 part in a million (by weight of sand) contained 330 parts per million (by weight of their air-dry tissues) after growing 1 month. Some of the plants were allowed to mature. The leaves then contained only 40 parts per million, the stems 12 parts per million, and the grain 8 parts per million.

Even this small amount was sufficient to make the grain toxic to white rats.[5]

When a crop like alfalfa, clover, or grass on an artificially selenized soil was repeatedly cut and allowed to grow up again with no further additions of selenium, the amount of selenium found in successive cuttings of similar age became progressively less, suggesting the gradual depletion of the selenium in the soil. Such decreasing concentrations in the tissues of successive crops from the same roots are shown in table 3.

TABLE 3.—*Selenium in successive crops cut at intervals from the same roots, in greenhouse plots treated with sodium selenate at a rate of 5 parts of selenium per million of soil.*[1]

Crop	Date of cutting				
	Mar. 5	Apr. 13	June 13	Aug. 2	Oct. 1
Sweet clover	645	400	195	93	85
Alfalfa	560	330	193	125	85
Wheat grass	255	150	145	40	60

[1] Analyses by A. Van Kleeck, U. S. Bureau of Chemistry and Soils, and by R. B. Deemer and R. F. Gardiner under the direction of Drs. E. C. Shorey and P. R. Dawson, U. S. Bureau of Plant Industry.

Not all elements in the soil are taken up as readily as selenium. The accumulation of a given element depends on the nature of the absorbing mechanism, which permits one substance to enter in greater amount than another. This capacity to control to some extent the materials entering the plant is known as "selective permeability", and it would seem that the mechanism involved should be such as to keep out a poison, like selenium, which so far as we know now is of no use to the plant. It seems quite possible that the easy entrance of selenium may be due to its chemical similarity to sulphur. Sulphur is essential to plant growth, being a constituent of the proteins and other compounds necessary to the plant's metabolism. Selenium and sulphur are closely related with respect to their chemical properties. It does not seem unreasonable, therefore, to assume that selenium gets in with sulphur, so to speak, and that they enter in proportion to their relative availability in the substratum.

The most striking evidence of such an interrelationship between sulphur and selenium appeared in the fact that when excess sulphur was made available to the plant the symptoms of selenium injury that developed otherwise could invariably be prevented (pl. 3, fig. 1). By means of sulphur treatments of both naturally seleniferous and artificially selenized soils the entrance of selenium into the plant

[5] The analyses for selenium content were made by W. O. Robinson, U. S. Bureau of Chemistry and Soils. The feeding tests on white rats were carried on in the laboratories of Dr. Hazel Munsell, U. S. Bureau of Home Economics.

was markedly reduced, although in no instance was it entirely prevented (Hurd-Karrer, 1935). The proportionate amount of selenium entering apparently decreases as the proportionate amount of available sulphur increases. Of course, to have this effect elemental sulphur must become available to the plant, largely through the action of the soil organisms that convert it to soluble sulphates.

Typical demonstrations of the inhibition of selenium injury to the plant by the addition of sulphur in the form of sulphate to quartz sand cultures are illustrated in plates 2 (fig. 2) and 3 (fig. 2). In the experiment shown in plate 3 the plants were grown with 0.033 gram of sodium selenate added to each pot of sand. The sand in the different pots was kept moist with nutrient solutions containing different concentrations of sulphur in the form of magnesium and ammonium sulphates. The plants with the nutrient solution containing no sulphate died in the seedling stage (*a*), those with a small amount were extremely chlorotic and stunted (*b*), those with a moderate amount were but slightly chlorotic (*c*), while those supplied with a large amount showed no chlorosis (*d* and *e*) and were as good as the corresponding controls without selenium in both height and development. Chemical analyses of the plants of two such experiments showed that selenium absorption was reduced by the excess sulphate to about one-fourth that of plants with little or no sulphate.

It was apparent from such experiments that the toxicity of selenium for plants is determined not by the absolute amount of selenium present but by the proportionate amount with reference to sulphur. To determine the critical ratio of the two elements—that is, the relative amount of sulphur necessary to prevent injury from a given amount of selenium—I grew wheat seedlings in flasks containing nutrient solutions. These solutions were all of the same composition with respect to the essential ions potassium, calcium, magnesium, phosphorus, nitrogen, and iron; but the sulphur, in the form of sulphate, was varied in the different series. In some none was added,[6] causing the plants to be a pale green but not greatly stunted or otherwise injured by the sulphur deficiency over the 5 weeks' period of the experiment. The highest sulphur concentration used was 192 parts per million, which was slightly toxic as shown by a perceptible reduction in height of the control plants. The selenium (as sodium selenate) was varied in the different flasks of each series in order to determine the amount necessary to injure the plants at each sulphur level. Growth of the plants in 3 of the 6 series is shown in plate 4.

[6] There was probably about 1 part per million of sulphur in these cultures from extraneous sources, such as impure chemicals and fumigants used in the greenhouse.

TABLE 4.—*The toxicity of selenium for wheat seedlings in relation to the sulphur (as magnesium and ammonium sulphate) in the nutrient solution (injury indicated by plus signs)*

Selenium (in parts per million) as selenate	Degree of injury to plants grown with the following concentrations of sulphate-sulphur (in parts per million)				
	0	10	32	96	192
0	0	0	0	0	0
0.01	0	-----	-----	-----	-----
.03	0	-----	-----	-----	-----
.05	0	-----	-----	-----	-----
.1	+	-----	-----	-----	-----
.2	+++	0	-----	-----	-----
.4	++++	0	-----	-----	-----
.6	+++++	0	-----	-----	-----
.8	+++++	0	-----	-----	-----
1.0	Dead	+	0	-----	-----
2	-----	+++	0	-----	-----
3	-----	++++	+	-----	-----
4	-----	Dead	++	-----	-----
5	-----	Dead	+++	-----	-----
6	-----	-----	++++	-----	-----
8	-----	-----	++++	0	-----
9	-----	-----	-----	0	-----
10	-----	-----	-----	+	-----
11	-----	-----	-----	++	-----
12	-----	-----	+++++	++	0
14	-----	-----	-----	+++	0
16	-----	-----	Dead	-----	0
18	-----	-----	-----	-----	+
20	-----	-----	-----	++++	++
24	-----	-----	-----	-----	+++
30	-----	-----	-----	+++++	++++
48	-----	-----	-----	Dead	+++++
96	-----	-----	-----	-----	Dead

The protective action of sulphur in the several such experiments may perhaps be most strikingly summarized by saying that the quantity of selenium necessary to kill the plants varied from about one part in a million, where no sulphate was added, to nearly 100 times as much where there was the most sulphate—i. e., 192 parts of sulphur per million. Moreover, there was a definite relation between the quantity of sulphate sulphur in the nutrient solution and the quantity of selenium required to produce a given effect on the plant (table 4). Thus the presence of 12 times as much sulphate sulphur as selenium always prevented injury regardless of the absolute amount of selenium supplied. Where there was only about 10 times as much sulphate sulphur as selenium, slight stunting and traces of the white chlorosis appeared on the leaves. Where there was but twice as much sulphur as selenium, the plants eventually died.[7]

In these experiments (table 4 and pl. 4) the sulphur (as sulphate) of a given series was the same in each flask, the selenium content being varied. They were repeated with the selenium constant in

[7] These ratios cannot be used to predict toxicity in soils because the soil analyses on which they would of necessity be based do not show what concentrations are actually available to the plant.

each flask of a series and the sulphate variable. One of these series is shown in plate 5. The fact that the selenium-sulphur ratios associated with the different degrees of injury to the plants were the same here as in the preceding experiments, although the nutrient solutions were of such different composition, increased the certainty and significance of an exact quantitative relation between sulphur availability and selenium toxicity.

Of course, there is the possibility that with some entirely different set of conditions the absolute values of these ratios might be changed somewhat. However, the environment was changed purposely in the different experiments over a period of several years by growing the plants at different times of the year and at different temperatures, by varying the composition and the acidity of the nutrient solutions, and by renewing the solutions after each week with some and after 5 weeks with others. The critical sulphur-selenium ratio for the appearance of visible injury varied only between 9 and 11. No relationship of this nature has been established for any other pairs of elements, the calcium-magnesium antagonism approaching it most closely, perhaps, but apparently not with this high degree of reproducibility.

The only way I have found so far to explain the relationship of sulphur and selenium is to assume that the root cannot tell the difference between them because of their chemical similarity. Assuming that this is true, then the amount of selenium taken in with a given amount of sulphur would depend on the proportionate amounts of the two which are available, the total absorbed being limited. Thus if there is a large excess of sulphur the root will get relatively little selenium. After the selenium gets in, it can be assumed that the plant proceeds to use it as if it were sulphur, but with serious results. Every molecule that gets selenium instead of sulphur would be disabled, as it were, and fail to function normally. When a large enough proportion of the molecules are affected the plant shows external signs of injury. This theory of substitution adequately accounts for the quantitative aspects of the dependence of selenium toxicity on relative rather than absolute sulphur availability; and for the fact that chemical analyses show that excess sulphur reduces the amount of selenium taken up by the plant.

The nature of the white chlorosis, which is typical of selenium injury to such plants as wheat and barley, suggests that some of the molecules susceptible to this substitution are involved in the synthesis of the green coloring matter, chlorophyll. Thus if the plastids were disabled by such a substitution in their protein molecules, then they might not function and the tissues would be white instead of green. It is interesting that one of the earliest experimenters with the effect

of selenium on plants (Cameron, 1880) postulated that the injury was due to substitution of selenium for sulphur in some essential compound in the tissues.

Regardless of the hypothesis to explain it, the tendency of an excess supply of sulphur to reduce the amount of selenium taken up by plants may have some practical value. As a demonstration of this possibility, I grew wheat plants in outdoor soil plots to which selenium (as sodium selenate) was added at a rate of 2 parts of selenium in a million of soil, mixed in to a depth of 6 inches. This is an amount of selenium equal to the weight of about 20 grains of wheat mixed into a soil mass weighing considerably over half a ton. Into some of the plots was mixed ordinary flowers of sulphur at a rate corresponding to three-fourths of a ton to the acre. When the grain was ripe, its toxicity was tested by feeding it to white rats (Hurd-Karrer and Kennedy). That from the plots receiving selenium alone stunted the rats and produced the damaged liver typical of selenium poisoning, whereas that from the plots that had received sulphur with the selenium permitted normal growth and produced no detectable symptoms of poisoning (pl. 6). Gypsum (calcium sulphate) was similarly effective in rendering the grain nontoxic.

Whether this effect of sulphur will supply the farmer with a practical means of control or of amelioration of the disease caused by selenium awaits testing under field conditions in the affected areas. It is quite possible that the high cost of even the cheapest form of sulphur may make the treatment of poorly productive land unfeasible.

One of the consequences of the theory that I have suggested to explain the selenium-sulphur relationship is that the more sulphur a plant normally requires in its metabolism, the more selenium it will take in. It is well known that some types of plants require more sulphur than others. Thus the plants of the mustard family, such as cabbage, broccoli, kale, and cauliflower, utilize a great deal to form the sulphur-containing compounds that give them their characteristic tastes and odors. They use so much that the sulphur of the soil must be replenished if such crops continue to be grown. Plants of the grass family require very little, so that they can be grown year after year without producing a deficiency of sulphur in the soil. It was therefore of both theoretical and practical interest to find that when representatives of these groups were grown in selenized soil, the selenium they took up paralleled their sulphur absorption. In table 5 are reported a few of the data that have been obtained showing this parallelism. The high sulphur absorption of representatives of the Cruciferae (mustard family) is invariably associated with a high selenium intake, and the lower sulphur ab-

sorption of the cereals is associated with a lower selenium intake. The Leguminoseae (legume family) have in general been intermediate (table 2).

Obviously, then, the safest crops to grow on seleniferous soils are cereals and grasses; and these are the crops that are chiefly raised on them now. Since all plants require sulphur, there is little likelihood of any plant being entirely unable to take up selenium.

That certain plants accumulate more selenium than others was first observed by Byers, who found that a certain wild aster (*Aster multiflorus*) growing in the seleniferous-soil areas (South Dakota) always contained more selenium than did the other vegetation. Shortly thereafter Beath and his coworkers (1934) found that certain plants in a different area (Wyoming) also absorbed it at an extraordinary rate. One species of *Astragalus* was found to take up as much as a tenth of 1 percent of the air-dry weight of the tissues, apparently without injury (Beath, Draize, Eppson, et al., 1934a). Byers (1935) subsequently showed that *Astragalus bisulcatus* consistently absorbed several hundred times as much selenium as another species of the same genus (*A. missouriensis*) growing beside it. He found the enormously high selenium concentration of 9,120 parts per million in *Oonopsis condensata.*

TABLE 5.—*Comparative absorption of selenium and sulphur by some crop plants grown in greenhouse plots to which 5 parts per million selenium (as sodium selenate) was added to the soil. (Figures are parts per million based on air-dry weight of tissues)*[1]

Plant	Selenium in plants	Sulphur in plants
Broccoli	1,330	32,300
Oats	740	14,800
Barley	640	13,600
Wheat	550	12,200
Spinach	430	9,000

[1]Analyses made under the direction of Dr. E. C. Shorey, U. S. Bureau of Plant Industry.

Although selenium-containing grain seems to be normal, animals to which it is fed are able to detect something in it they do not like. The rats of the grain-feeding experiments (Hurd-Karrer and Kennedy) invariably refused to eat much for about a week, although later they ate normal amounts. However, others persisted indefinitely in their refusal to eat. Thus some young spinach grown in selenized soil in the greenhouse and containing between 300 and 400 parts per million selenium remained almost untouched, the rats preferring to starve for the 3-day intervals during which it was left in their cages. This spinach was fresh and succulent and with every outward appearance of being desirable food. But the rats detected the presence of the selenium, for when market spinach was sub-

stituted they immediately recognized the difference and ate voraciously.[9] Other experimenters have reported a similar disinclination to eat selenium-containing materials on the part of larger animals as well as of rats (Franke, 1934; Munsell).

The higher animals are not the only creatures that show extraordinary sensitiveness to traces of selenium. Red spiders are reported to be very susceptible to selenium-containing insecticides. The aphids or plant lice that infested the healthy wheat in some of my experiments were never observed on those plants that were visibly injured by selenium. When selenium was supplied to the roots of plants already infested, the plant lice left. The number of aphids on the plants varied so consistently with the amount of selenium in the nutrient solution as to suggest that they might indicate the relative amounts of selenium in the plants with an accuracy comparable to that of chemical analyses. It is interesting that algae grew well in the solutions nourishing the plants on which the plant lice died; and wheat mildew (*Erysiphe graminis*) and smut (*Tilletia tritici*) attacked wheat plants containing relatively large amounts of selenium (several hundred parts per million).

Whether man is susceptible to ills attendant upon a selenium-containing diet is not known. There have been occasional reports of abnormalities of human beings in the seleniferous areas suggestive of the symptoms of the poisoning in animals. But probably the danger is slight, especially outside the affected areas, because of the diversity of the normal human diet.

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[9] These feeding tests were conducted under the direction of Dr. H. E. Munsell, U. S. Bureau of Home Economics.

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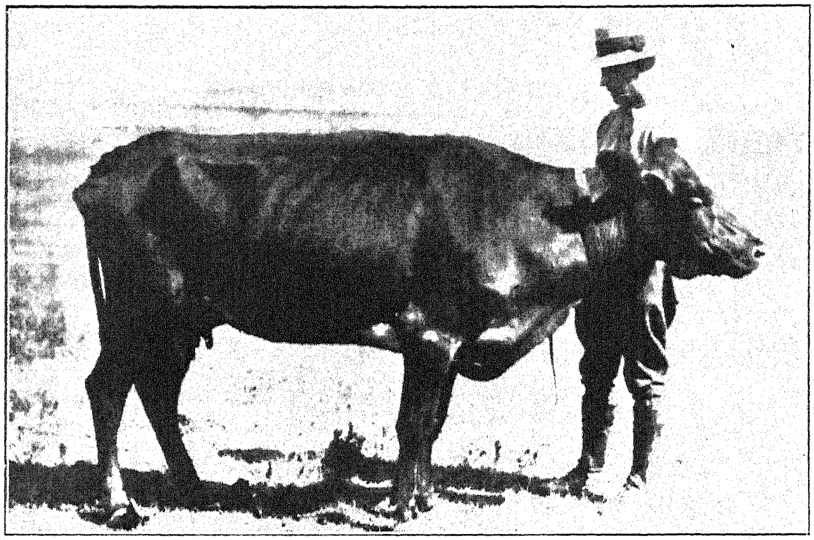
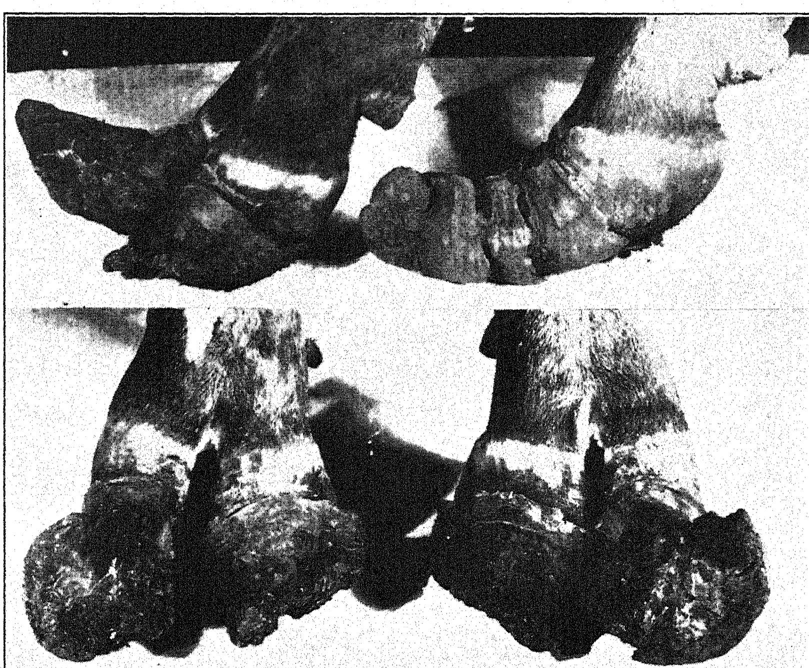
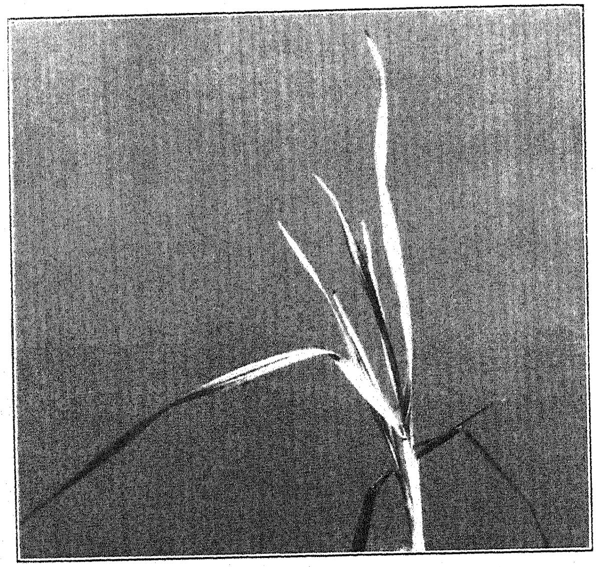


1. Cow poisoned by foodstuffs containing selenium.



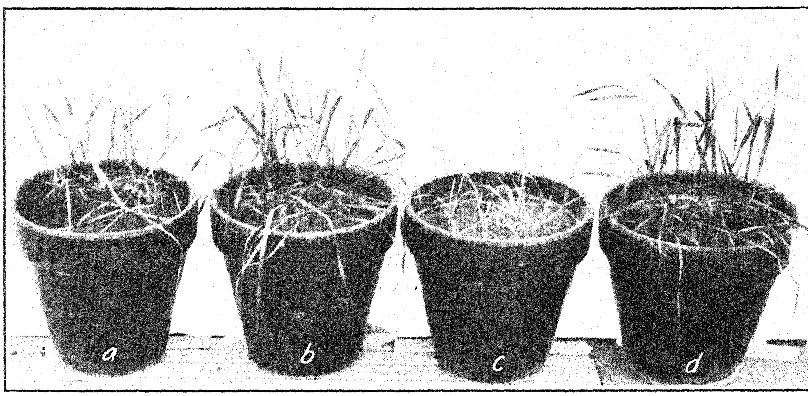
Reproduced from Circular 320, U. S. Dept. of Agriculture.

2. Deformed hoofs of cow in above picture.

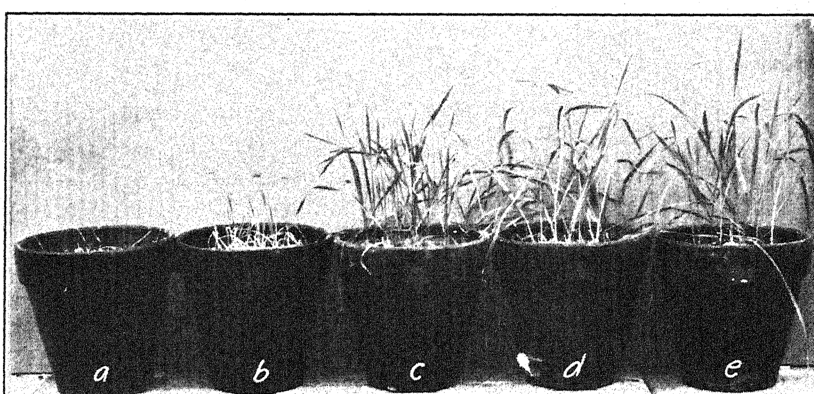


1. Plant poisoned by selenium, showing white chlorosis.

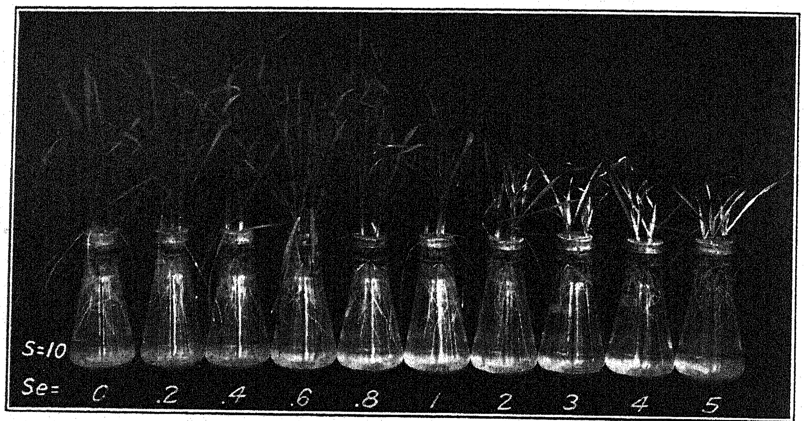
2. At left, selenium injury to wheat seedlings in quartz sand. At right, plants given same amount of selenium but protected from injury by excess sulphate.



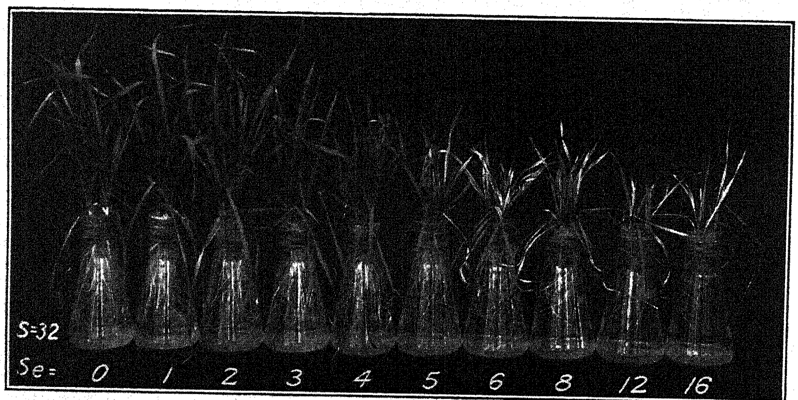
1. Prevention of selenium injury to wheat plants by elemental sulphur treatments of selenized soil. (*a*) Plants in Pierre clay injured by the addition of 10 p. p. m. selenium as sodium selenate; (*b*) uninjured where excess sulphur was added also; (*c*) injured by 20 p. p. m. selenium; (*d*) uninjured where excess sulphur was added also.



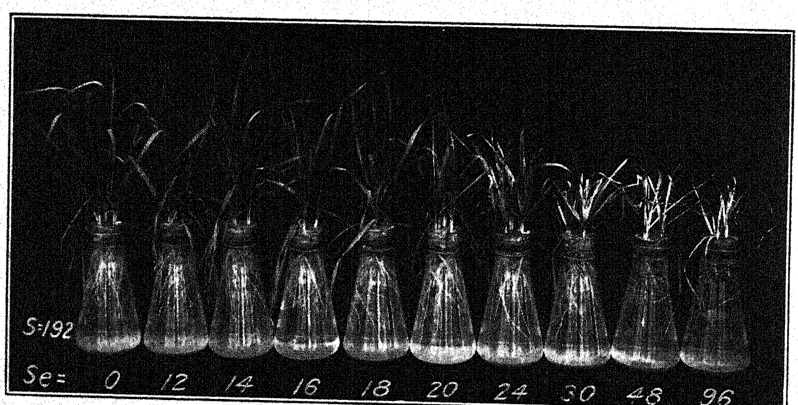
2. Wheat plants growing in quartz sand containing 0.033 gram of sodium selenate per 7,000 grams of sand and differing amounts of sulphate sulphur (as magnesium and ammonium sulphates). The plants are dead with no sulphate (*a*), almost dead with sulphate supplying 10 p.p.m. sulphur (*b*), chlorotic with 32 p.p.m. (*c*), and normal with 96 and 192 p.p. m. (*d* and *e*).



1. Plants in nutrient solutions containing 10 p. p. m. sulphate sulphur injured by 1 p. p. m. selenium.



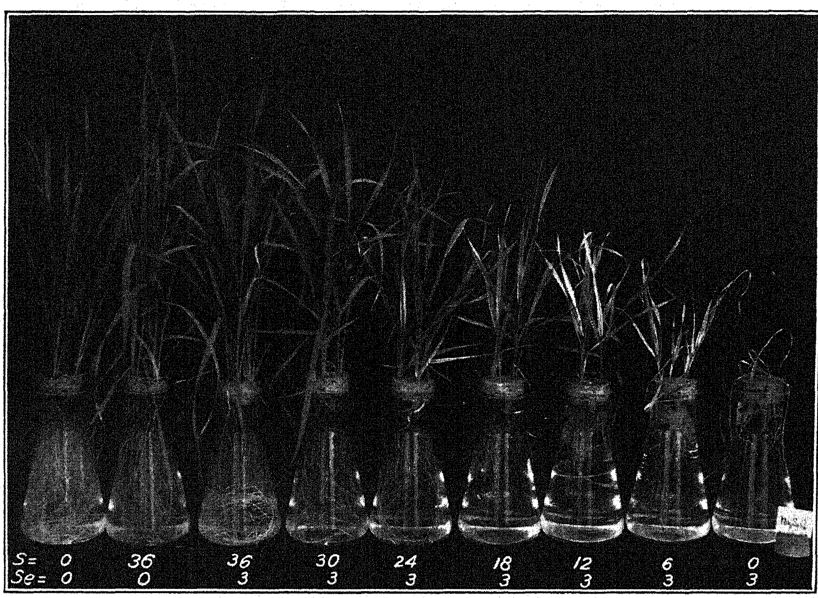
2. Plants in nutrient solutions containing 32 p. p. m. sulphate sulphur uninjured by 2 p. p. m. selenium, injured by 3 p. p. m. selenium.



3. Plants in nutrient solutions containing 192 p. p. m. sulphate sulphur uninjured (except for slight stunting from excess sulphur) by 16 p. p. m. selenium, injured by 18 p. p. m. selenium.

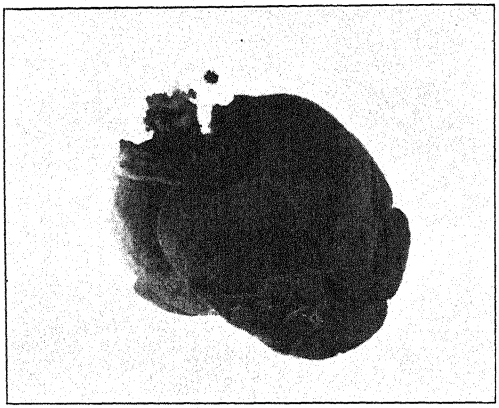
DEMONSTRATION OF A CRITICAL SELENIUM-SULPHUR RATIO WITH WHEAT PLANTS GROWN IN NUTRIENT SOLUTIONS CONTAINING 10, 32, AND 192 P. P. M. SULPHUR AS MAGNESIUM AND AMMONIUM SULPHATES, AND VARIOUS SELENIUM CONCENTRATIONS.

Figures under flasks denote parts per million selenium as sodium selenate.

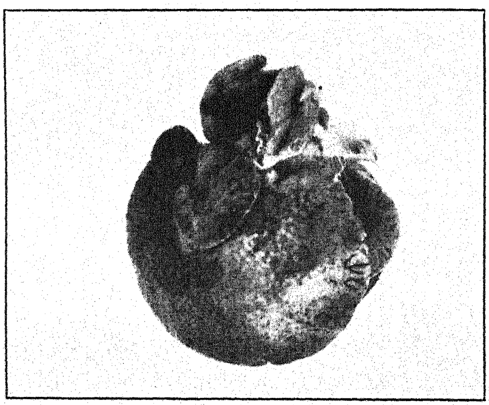


RELATION BETWEEN SELENIUM TOXICITY TO WHEAT AND THE AMOUNT OF SULPHATE SULPHUR IN THE NUTRIENT SOLUTION.

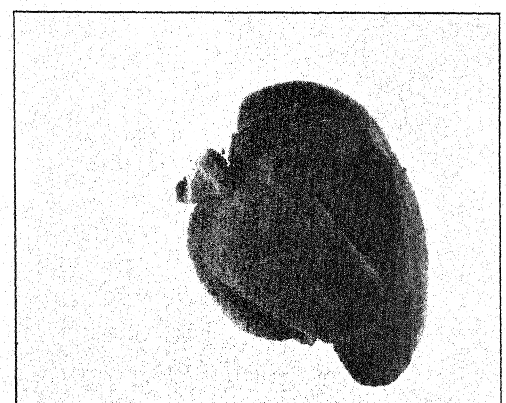
The plants to the extreme right are killed by 3 p. p. m. selenium (as sodium selenate) in the absence of sulphur. From right to left the plants show decreasing injury from this amount of selenium as the sulphate increases, until the plants become normal with 36 p. p. m. sulphur. (The first control culture to the extreme left shows injury from sulphur deficiency.)



1. Normal liver (control).



2. Liver produced by wheat grown with 2 p. p. m. selenium (as sodium selenate) added to the soil.



3. Liver of rat fed wheat grown on selenized soil like that producing the grain for the rat in figure 2, but with an application of sulphur at the rate of 1,500 pounds per acre. The liver appears normal in every respect.

COMPARATIVE DEVELOPMENT OF THE LIVERS OF WHITE RATS FED WHEAT GROWN ON SELENIZED SOIL WITH AND WITHOUT APPLICATIONS OF SULPHUR.

THE GLACIAL HISTORY OF AN EXTINCT VOLCANO, CRATER LAKE NATIONAL PARK[1]

By Wallace W. Atwood, Jr.,
Clark University

[With 6 plates]

THE GLACIO-VOLCANIC SEQUENCE

Hidden away in the volcanic rocks of the Cascade Range of southern Oregon is the record of Mount Mazama, an ancient volcanic cone that grew to great height and later disappeared entirely, leaving a giant caldera in which the deep-blue waters of Crater Lake have since accumulated (pl. 1). The story of this mysterious mountain is recorded in the rocks of the region. Like leaves in a book, the alternating layers of laval and glacial material in the rim surrounding Crater Lake tell the story of the late monarch of the Cascade Range.

During the vulcanism of mid-Tertiary time small volcanic cones developed in the Cascade region, one of which was destined to become Mount Mazama (fig. 1). With continued igneous activity the youthful mountain attained sufficient altitude to cause heavy precipitation on its slopes. Snows accumulated and remained through succeeding seasons. Glaciers were born, and the ice fields moved slowly down the slopes of the intermittently active volcano (fig. 2). Evidence of these early glaciers is found in the form of till deposits buried beneath several hundred feet of volcanic material and younger glacial debris.

Glaciers on the slopes of a volcano sooner or later are apt to fall victim to renewed lava eruption. In the case of young Mount Mazama, the glaciers were destroyed several times during the growth of the mountain. The glacial landscape of figure 2 was changed to the volcanic landscape of figure 3. Gradually this activity subsided and the scene reverted to a glacial landscape (fig. 4). This succession of changes may be called the "glacio-volcanic sequence." While the pen-and-ink sketches show only one sequence, the glacial deposits

[1] Reprinted by permission, with slight alterations, from the Journal of Geology, vol. 43, no. 2, February-March 1935.

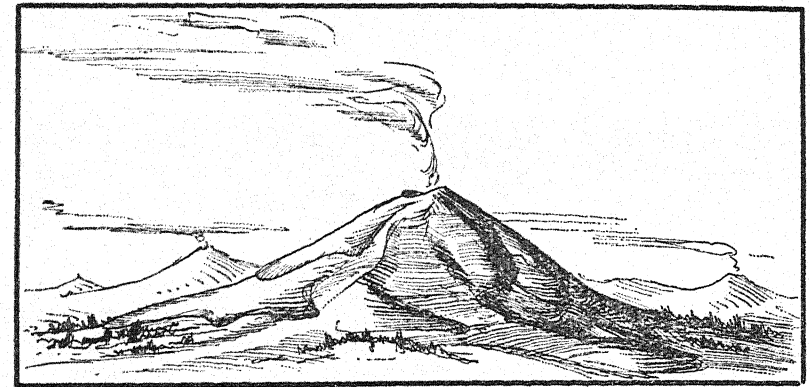


FIGURE 1.—The youthful Mount Mazama as it may have looked during the early stages of its growth. Continued volcanic activity gradually produced a mountain.

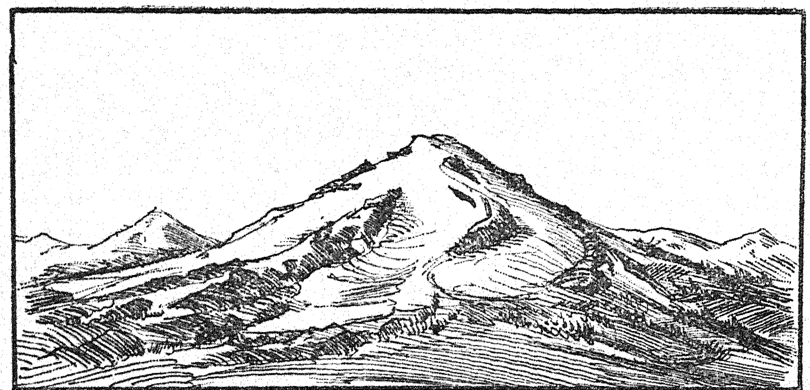


FIGURE 2.—A later stage in the growth of the volcano. The cone is dormant and small glaciers are present. Successive stages of vulcanism and glaciation followed.

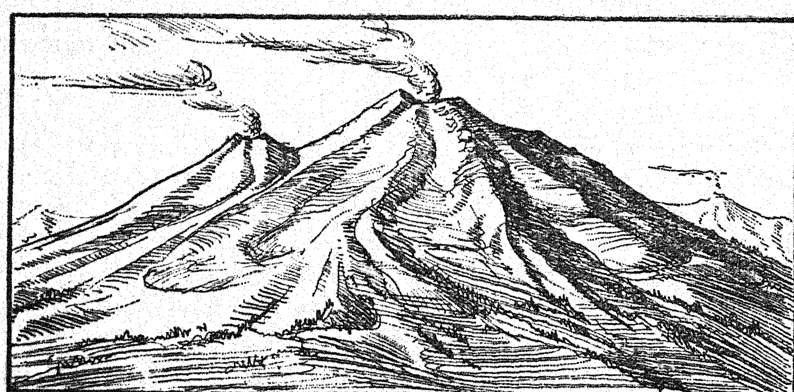


FIGURE 3.—Mount Mazama during one of its last periods of volcanic activity. A secondary cone, Little Mazama, is situated on the western slope.

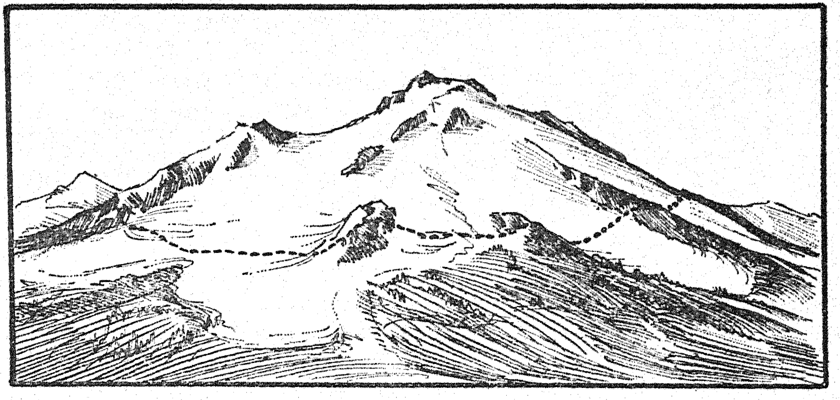


FIGURE 4.—The last glacial landscape. The U-shaped valleys which notch the present rim were produced during this final ice invasion. The dotted line indicates the location of the rim.

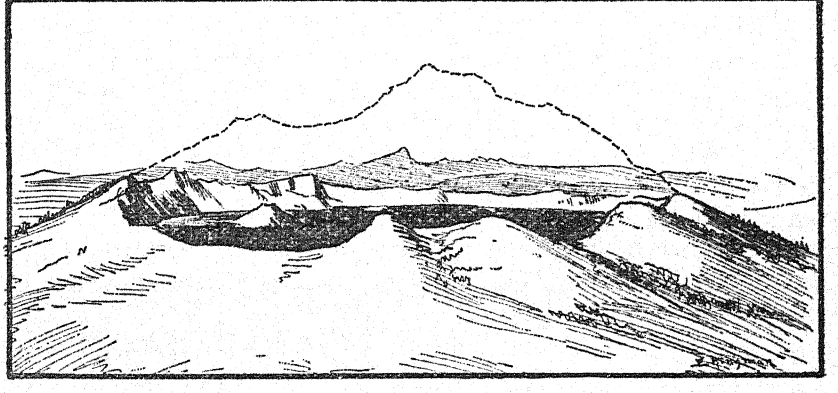


FIGURE 5.—The present Crater Lake located in the giant caldera, formed by the collapse and engulfment of Mount Mazama. The Wizard Island cinder cone developed after the disappearance of the mountain.

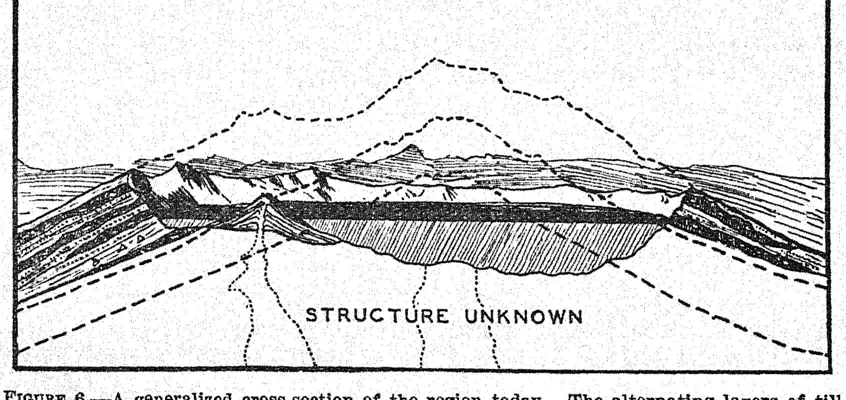


FIGURE 6.—A generalized cross-section of the region today. The alternating layers of till and volcanic material record the story of the growth of Mount Mazama. The dotted lines mark the several stages represented in the preceding drawings.

exposed in the rim surrounding the present lake indicate that four, and possibly many more, stages of glaciation were interspersed with the periods of vulcanism. This continued glacio-volcanic sequence is suggested in figure 6.

It will be noted from the sketches that the mountain at first had but one cone, while during the later stages of volcano building a secondary cone developed. This smaller mountain is Little Mazama. The absence of this cone during the glacial stage illustrated by figure 2 and its existence during later stages in the growth of the mountain are determined by the direction of striae markings found buried at different levels beneath lavas and glacial debris (see figs. 12 and 13).

Without discussing at this place each of the glacio-volcanic sequences, we arrive at the stage in the growth of the mountain represented by figure 4. The volcano was apparently dormant, and large glaciers radiated from the summits of Mount Mazama and Little Mazama. While these glaciers still existed, there commenced a gradual destruction of the cone. Renewed volcanic activity produced a shower of pumice which whitened the entire landscape. Many of the high points on the rim, as well as the morainic deposits left by the last glaciers, are still partially buried beneath this pumice. But in spite of the enormous amounts of this fine debris scattered over the landscape, the disappearance of the entire mountain mass above the dotted line in figure 4, and much of the core to a depth of 3,000 to 4,000 feet below the present rim, cannot be explained by explosive eruption alone.

Approximately 15 cubic miles of material have disappeared in order to produce the landscape shown in figure 5. If explosion accomplished this great change, we would expect to find a thick mantle of fragmental andesitic lava and breccia scattered over the surrounding countryside. Furthermore, the glacial deposits, formed by the glaciers which existed only as long as the mountain existed, should be heavily buried with the fragmental material derived from the destruction of the mountain. Instead we find very little angular material in the region, and most of that had its origin prior to the last glaciers which existed on the mountain before its destruction.

The possibility that Mount Mazama never became a high volcanic cone was carefully considered in the field. If the mountain had not exhibited evidence of recurrent glaciation, the existence of a high cone would have been difficult to establish. However, since glacial evidence is unmistakably present and, furthermore, since the Pleistocene glaciers of the Cascade Range were restricted to the higher mountains, it is logical to conclude that Mount Mazama attained a height comparable to the peaks of the Cascade Range

which carried glaciers during that period. On the basis of the glacial record, the approximate height of Mount Mazama has been established.

Unlike Krakatoa and Katmai, Mazama did not blow itself to pieces; but instead, it is believed, this mountain collapsed and was engulfed. As early as 1901 Joseph S. Diller proposed this theory in his presidential address delivered before the Geological Society of Washington.[2] A year later the results of Diller's field work appeared as a professional paper of the United States Geological Survey.[3] Although it is difficult to conceive of such a phenomenon, field evidence to date affords no acceptable alternative. The mountain certainly existed; the mountain is now gone, and the 15 cubic miles of material have not been found. The processes of engulfment were probably slow. They may have been similiar to the caving-in which takes place in Hawaii, where the huge calderas are from time to time being enlarged by engulfment.

Following the formation of the giant caldera near the close of the Pleistocene, or shortly thereafter, there was a brief period of inactivity interrupted by the building of Wizard Island cinder cone and two other smaller cones reported to exist on the floor of the present lake. Since the completion of the Wizard Island Cone, there has apparently been no volcanic activity in the immediate region.

With the cessation of vulcanism a lake formed in the bottom of the caldera. The annual precipitation far exceeded the amount of water lost each year by evaporation and seepage, and consequently the lake level rose. Crater Lake is now nearly 2,000 feet deep, and it maintains a relatively constant level throughout the year. A certain amount of water disappears through underground channels and reappears in numerous springs on the lower slopes of the mountain base.

IMPORTANT LOCALITIES

In order to unravel the long and complicated history of Mount Mazama, many field observations were made on the precipitous cliffs surrounding the lake. A few of the significant localities will be described and related to the glacio-volcanic sequence which preceded the collapse and engulfment. The locations of all exposures mentioned are shown on the reference map, figure 7.

Discovery Point (1).—On the rim at Discovery Point, partially covered by overlying pumice material, are several beautiful polished

[2] Diller, J. S., The wreck of Mount Mazama, abstract published in Science, n. s., vol. 15, pp. 203–211, January–June 1902.

[3] Diller, J. S., and Patton, H. B., The geology and petrography of Crater Lake National Park. U. S. Geol. Surv. Prof. Paper 3.

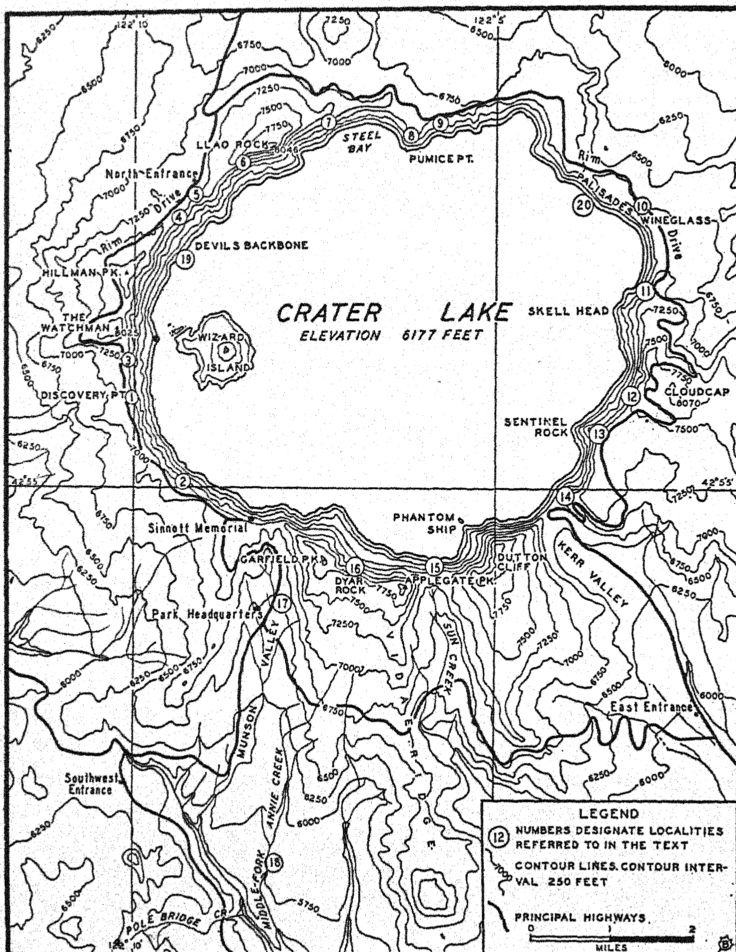


FIGURE 7.—Index map of the Crater Lake Region.

and striated rock surfaces (pl. 3, fig. 1).[4] The existence of these striae on the surface lavas indicates that glacial ice crossed this portion of the rim following the last lava eruption.

When standing on the striated surface close to the edge of the cliff, it is possible to look down approximately 40 feet to another glacially polished surface. Upon investigation it is discovered that these glacial scratches are covered with 10 feet of boulder till, and that the till is, in turn, capped with 30 feet of lava. This relationship is best shown in plate 3, figure 2. How did the glacial material become sandwiched in between flows of lava? The answer is

[4] All photographs, unless otherwise credited, are official pictures of the National Park Service.

wrapped up in the growth of Mount Mazama. The lower glacial horizon is related to a stage of glaciation which was abruptly terminated when the mountain erupted the lavas which now cap the till deposits. The upper glacial horizon dates to the last glacial stage which occurred after the surface lavas had cooled and before the mountain collapsed.

Identification of the striae and glacial till deposits which occur over and over again within the Crater Lake region has been made only after considering all alternative possibilities. Structure within the volcanic rocks has been carefully eliminated as a factor in producing the polished and grooved lava surfaces. It should be stated, however, that certain exposures exhibit scratches which are definitely due to causes other than glaciation. All such exposures have been eliminated from consideration in the present study. The recognition of till deposits has been made on the basis of physical and lithologic composition and on the existence of subangular and striated stones. While the writer is aware of the difficulties associated with the identification of glacial scratches, he feels certain that the variety and kind of evidence available at Crater Lake points conclusively to a glacial origin for the features here described.

Glacier Point (2).—Close to the trail which follows the rim east of Discovery Point is an excellent exposure illustrating three stages of glaciation. Three lava flows of different ages exhibit striae (fig. 8). The lower surface is capped with till containing subangular and striated stones, while the other levels are relatively free of glacial debris.

South of the Watchman (3).—About half way between Discovery Point and the Watchman, resting upon a striated lava surface, is a thin layer of glacial till and in turn some 50 feet of stratified pumice and fragmental material. In the pumice is a carbonized log standing in upright position. The stump and roots appear to have decomposed, allowing a portion of the log to settle. D. S. Libbey, the park naturalist, in collaboration with Albert E. Long, excavated the log during the summer of 1933. It is believed that the tree was growing in a thin layer of glacial till when volcanic ash and pumice buried it. The roots and base of the tree were buried first by cool pumice, but subsequently hot volcanic ash and pumice settled around the tree so fast that air was excluded, combustion was prevented, and carbonization resulted [5] (fig. 9).

North of the Devils Backbone (4).—Beside the rim road a short distance north of the Devils Backbone is a beautifully polished and striated surface of lava (pl. 4, fig. 1). Resting upon this is a thin layer of till and a deposit of pumice, locally several feet thick and

[5] Libbey, D. S., Carbonized tree found within the rim. Nature Notes, Crater Lake National Park, vol. 6, no. 3, August 1933.

interbedded with angular fragments of andesitic lava. In places the pumice rests directly upon the well-striated surface.

Near North Entrance Ranger Station (5).—Beneath pumice and what appears to be a much-fractured lava formation is an old weathered surface which exhibits well-developed glacial grooves (pl. 4, fig. 2). The poor preservation of the surface and its buried location suggest that the markings are older than those found just north of the Devils Backbone. If talus material did not cover so much of the inner slope at this point, it would probably be possible to relate this

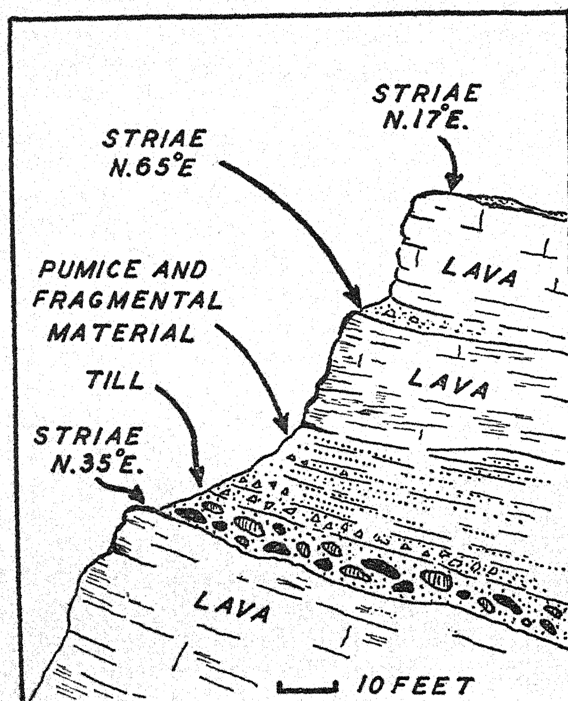


FIGURE 8.—Three stages of glaciation at Glacier Point. Locality 2.

grooving to the earlier of the glacial stages recognized at Discovery Point.

Llao Rock (6). —From a point on the rim just east of the North Entrance Ranger Station it is possible to view the steep front of Llao Rock. If one is equipped with a pair of good boots, it is possible to crawl along at the base of the steepest portion and reach a position marked *A* in plate 5, figure 1. Here, buried beneath the lava of Llao Rock, is a heavy boulder till containing numerous well-striated stones ranging from a few inches to a foot in diameter. The material is characteristically glacial in appearance. A few hundred feet farther down the slope, and several hundred yards to the

south, is a glacially polished bedrock surface overlain by boulder moraine. The position of these various evidences of glaciation beneath the dacite flow which produced Llao Rock is conclusive proof of glaciation on Mount Mazama prior to the eruption which produced the Llao Rock flow. From a vantage point on the lake or on the opposite rim, an excellent view of Llao Rock is obtained which shows very clearly the topography which existed before the Llao Rock flow descended the slopes of Mazama (pl. 5, fig. 2). On the basis of the glacial evidence reported above, the pre-Llao topog-

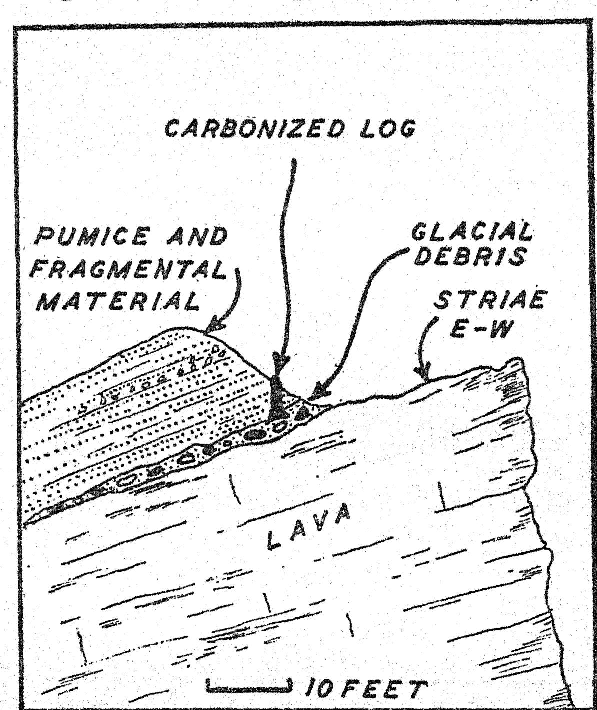


FIGURE 9.—A carbonized log buried beneath pumice and fragmental material. Locality 3.

raphy presented a glacial landscape and the U-shaped form of the central portion of the Llao flow is due to glacial scour in the valley, which was later occupied by the lava stream. Because of inaccessibility it was impossible to determine whether glacial material exists beneath the central portion of the flow.

Steel Bay (7).—After considerable difficulty a section was investigated at the western edge of Steel Bay. The very steep walls prevented complete examination, but the record uncovered was nevertheless of value. There are two distinctly striated surfaces—one buried beneath approximately 100 feet of pumice and the second several hundred feet down the cliff.

Pumice Point (8).—Across Steel Bay to the east is Pumice Point, easily identified from almost any position on the rim because of its large white pumice face. On closer inspection, however, it is discovered that there is more than pumice on Pumice Point (fig. 10). Interbedded in the volcanic material are layers of glacial till and old soil. The sequence of events has evidently been one of glaciation, vulcanism, and renewed glaciation, followed by an interval during which soil developed and then by another period of vulcanism.

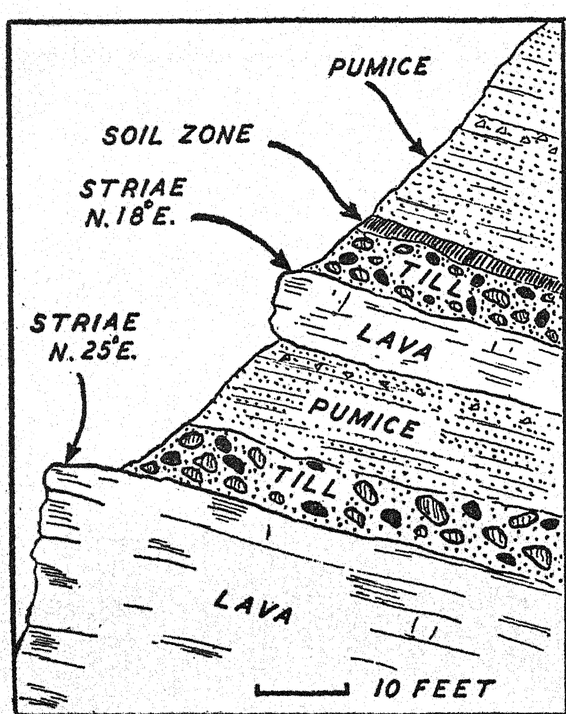


FIGURE 10.—Two glacial stages at Pumice Point. A soil zone appears in the upper portion of the younger till layer. Locality 8.

The upper portion of the younger till layer is a dark-colored soil zone containing an abundance of vegetal material, much of it charred. The existence of the soil layer on the steep pumice talus slope was first suggested by a band of vegetation which appeared on an otherwise barren hillside. By removing the veneer of pumice, the moisture-retentive soil zone was discovered. The relationships here are similar to those on the rim south of the Watchman, although the carbonized material at Pumice Point is limited to small fragments. Future excavations may uncover larger and better-preserved representatives which, it is hoped, can be identified. The real significance of the soil zone in the story of Mount Mazama is the time interval

implied. Like the periods of vulcanism and glaciation, the periods when soil developed and vegetation became established on the mountain required time. These records make it possible to reconstruct partially the time intervals in the growth of Mount Mazama. The lava surfaces exposed beneath the glacial till were well striated in a N. 32° E. direction.

Pumice Drive (9).—A short distance northeast of Pumice Point and 75 feet below the level of the highway is a layer of till 5 feet or more in thickness, containing many well-striated stones, some of them as much as 2 feet in diameter. The lava beneath the glacial material is so weathered that all record of striae has been long since destroyed. Above the till are 30 feet of stratified pumice followed by 10 to 15 feet of lava breccia and 30 feet of pumice. The conditions here suggest that considerable eruption followed the last glacial advance in this locality.

The Wineglass (10).—North of Cloudcap and east of the Palisades is an interesting feature known as the Wineglass. Viewed from the lake, the white talus material appears like a huge goblet, the constricted portion at the base of the bowl being produced by a resistant layer of columnar lava. Resting on this columnar lava is a deposit of glacial till consisting of a variety of volcanic rocks, many of them subangular and striated. Many of the larger stones are 2 feet in diameter. Above the till are approximately 20 feet of pumice followed by 10 to 15 feet of lava breccia and 25 feet of pumice. Bedrock striae were not observed at this locality.

Skell Head (11).—A short distance from the rim road northeast of Skell Head a thin deposit of glacial till rests upon striated bedrock. The till contains nicely rounded and striated stones, some of which suggest the work of water as well as of ice. Compass readings indicate that the ice moved in a N. 50° E. direction across the bedrock surface.

Cloudcap (12).—On the rim directly west of Cloudcap is a layer of pumice and fragmental material well over 100 feet in thickness resting upon a striated lava surface. Owing to the inaccessibility of the bedrock exposures and the advanced stage of weathering, only two striae readings were recorded, both indicating a N. 70° W. direction. Unlike most localities thus far discussed no layer of distinctly glacial material was found. Numerous subangular stones suggest that at least a portion of the fragmental material overlying the glacial surface was transported by ice.

Sentinel Rock (13).—A mile to the southwest of Cloudcap is Sentinel Rock, a promontory readily recognized from almost all outlook points on the rim. Here a resistant lava formation is buried under layers of pumice and fragmental material. In 1931 excellent

striae were located on a partially loosened block close to the edge of the cliff. By allowing for the amount of displacement, a reading of N. 75° W. was obtained. In 1933 the same locality was revisited, but the block had disappeared. In hopes of locating new exposures, search was made to the south along the contact between the lava and overlying fragmental material. While bedrock striae were not found, owing to the weathered character of the exposed rock, an excellent boulder moraine was discovered. The lower layer of fragmental material which was resting upon the lava at Sentinel Rock gave way to glacial till containing nicely polished and striated stones. Above the till was a thick layer of stratified pumice and occasional bands of coarser material. Even with absence of bedrock striae, evidence of a buried glaciation was convincing.

Kerr Notch (14).—On the steep cliff of Danger Bay, just north of Kerr Notch and 500 feet below the glacial material referred to above, is a second buried glacial deposit. Striated stones ranging from small pebbles to boulders 2 feet in diameter are common. The upper portion of the till is roughly stratified, suggesting that rains or glacial flooding accompanied the deposition. Above the glacial material is a layer of columnar lava followed by alternating layers of pumice and breccia; below it is a much weathered lava on which no striae were found.

In addition to buried evidence of glaciation, the U-shaped profile of Kerr Valley offers proof of ice action (pl. 5, fig. 3). Like the glaciated surfaces west of Cloudcap, the U-shaped floor of Kerr Valley is buried with stratified pumice and fragmental material. Since the stratification appears undisturbed, it is to be inferred that glaciers did not exist in these areas during or after the eruption of pumice. Judging from the heavy accumulation of pumice at Cloudcap, as compared with the 30–40 feet at Kerr Notch, glacial ice probably remained in the valley for some time after it had abandoned the higher land to the north.

Sun Notch (15).—Between Applegate Peak and Dutton Cliff is the broad U-shaped valley of Sun Creek (pl. 2, fig. 1). Below the usual layer of pumice is a striated lava surface over which the ice rode. At several locations between the highway and the rim morainic features were recognized, although most of them were more or less effectively buried by pumice and fragmental material. As at Kerr Notch, the relationships suggest that the glacier abandoned the valley prior to the last pumice eruptions.

Dyar Rock (16).—A short distance west of Sun Notch in the col between Garfield and Applegate Peaks a layer of glacial till rests upon a striated lava surface. Compass readings indicate that the ice proceeded in a N. 10°–20° E. direction. Above the till is a layer

of pumice and fragmental material similar to that found in Sun Notch to the east. Back from the rim where the till and pumice covering has been partially removed by wind and rain, some bedrock outcrops exhibit striae. One and a half miles south of the rim, close to the highway, good morainic topography indicates that glacial ice once covered part, if not all, of the slope west of Vidae Ridge.

Munson Valley (17).—Directly east of the Government camp and superintendent's office in Munson Valley is one of the best morainic evidences of glaciation to be found in the park. While striae are very scarce, the curving form of the ridges and their hummocky topography leave no doubt as to their glacial origin. Unlike most of the glacial features thus far reported, these moraines are not buried by pumice.

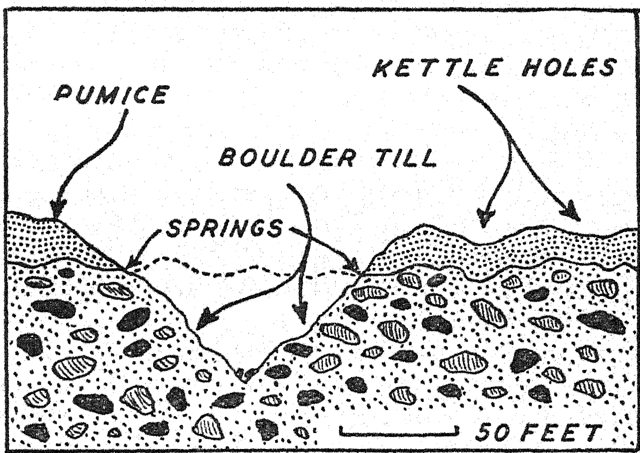


FIGURE 11.—Buried kame and kettle topography on the Middle Fork of Annie Creek. Locality 18.

Middle Fork Annie Creek (18).—Three miles south of the government camp between Middle Fork and Annie Creek is a most interesting topography resembling kame-and-kettle moraine. Directly opposite, on the other side of Annie Creek along the highway north of Pole Bridge Creek, is a similar topography. In both areas there are numerous hills of pumice separated by depressions in pumice. Not until a cross-section of the material was discovered in the valley of Middle Fork a little over a mile above the junction of that stream with Annie Creek did an explanation come to light (fig. 11). In the bottom of the V-shaped gorge were hundreds of large polished boulders that certainly did not originate from the pumice formation. On closer examination several of these boulders were found to be striated. With this clue a careful study was made of the walls of the gorge. The upper 20–30 feet were composed of dry pumice, while the lower

40–50 feet were soaking wet and grass-covered. Numerous springs issued at the top of the grassy portion, making it extremely difficult to negotiate the steep slope. The line of springs marks the top of relatively impervious morainic material from which the boulders in the stream bottom were derived.

The walls of this gorge provide the cross-section of the kame-and-kettle topography. With the underlying material identified as boulder till, it is safe to assume that the puzzling hills and depressions resulted from glacial deposition and that the pumice veneer is but a postglacial camouflage.

The full significance of this buried hummocky moraine may rest in its suggestion of the terminal position of the Munson Valley glacier. To be sure, there is no proof that the deposit does not represent a recessional stage of the glacier; and no evidence thus far obtained would deny a much more extensive glaciation than is here described. Some day the valley of Annie Creek may reveal new clues; but until definite evidence of ice action is found farther down the valley, there is no reason for assuming that ice proceeded beyond the position indicated on Middle Fork. The possibility of securing new evidence at greater distances from the rim is very slight in view of the vast pumice and ash deposits which bury so much of the former glacial landscape.

South of the Devils Backbone (19).—Within the rim just south of the Devils Backbone and only 300 feet above the lake level is the oldest record of glaciation discovered in the region (pl. 6, fig. 1). Buried beneath 800 to 900 feet of lava and volcanic material of various kinds is a deposit resembling till, although striae do not appear. Underlying this formation, however, is a striated bedrock surface indicating that even during the early stages of volcano building, the cone of Mount Mazama attained sufficient height to allow glaciers to form and descend to elevations of approximately 6,500 feet. One naturally wonders how high the mountain was during this early stage, but adequate evidence on which to base any calculation is entirely absent.

Palisades (20).—A short distance to the west of the Wineglass is a massive flow which produces a precipitous cliff 300 to 400 feet high, known as the "Palisades." At the foot of this cliff is a long talus slope underlain in part at least by heavy boulder moraine (pl. 6, fig. 2). Approaching the exposure from the lake, the subangular form of the boulders is the first characteristic to be noted. Closer inspection reveals striae. The surface on which the till rests is undoubtedly beneath the level of the lake. This glacial deposit is lower in elevation than any found within the rim, but it is not so deeply buried under volcanic material as the old striated surface south of the Devils Backbone.

PROJECTED STRIAE

In plotting the striae readings found on the rim, certain very interesting facts came to light. All striae that appeared to be associated with the last advance of ice were recorded on the map. This selection included the striae that were buried by pumice and fragmental material, but not those beneath lava flows. When the readings were complete, the lines indicating direction were projected toward the lake, with the result shown in figure 12. It is not safe to place too much significance on this type of mapping; nevertheless, certain results appear convincing. Most of the lines projected from readings on the north, south, and east rims roughly converge above the center of the lake. This fact, coupled with the volcanic evidence in the rocks surrounding the lake, suggests rather definitely that the summit of the original Mount Mazama was somewhere above the center of the present Crater Lake.

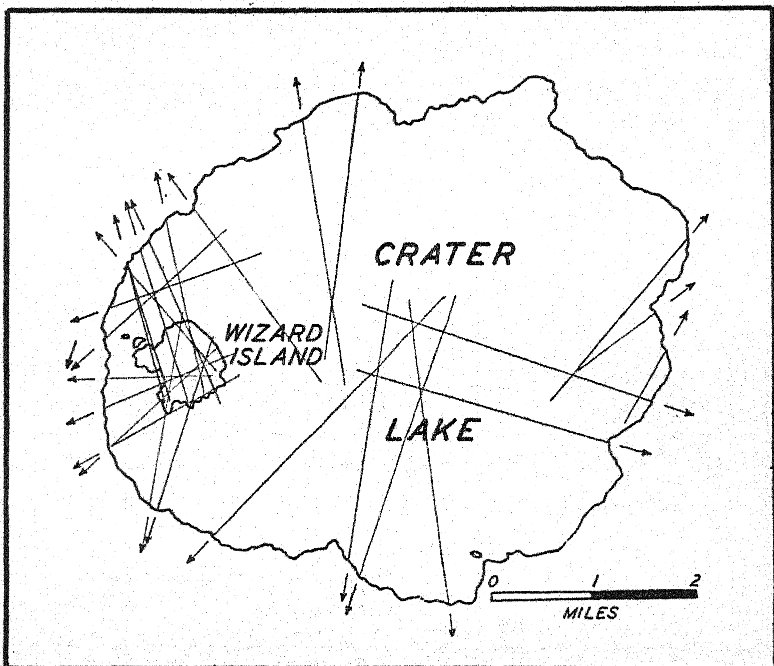


FIGURE 12.—The direction of ice movement during the final stages of glaciation on Mount Mazama. The projected striae suggest that there were two centers of ice dispersal—one somewhere above the middle of Crater Lake, and the other above Wizard Island.

A second center of intersection of projected striae appears over Wizard Island. This is certainly no mere coincidence but instead seems to prove the existence of a secondary cone which, like Shastina on the side of Mount Shasta, grew on the slope of Mount Mazama.

The ice which crossed the rim between Discovery Point and the Devils Backbone undoubtedly originated on this peak which once existed above the present Wizard Island (figs. 4 and 5). If this is the case, Wizard Island is probably the result of renewed activity from the same channel from which, in an earlier period, came the lava which produced Little Mazama.

Following this method of investigation a little further, another map has been constructed showing the direction of the striae which exist within the crater rim and are definitely related to the earlier

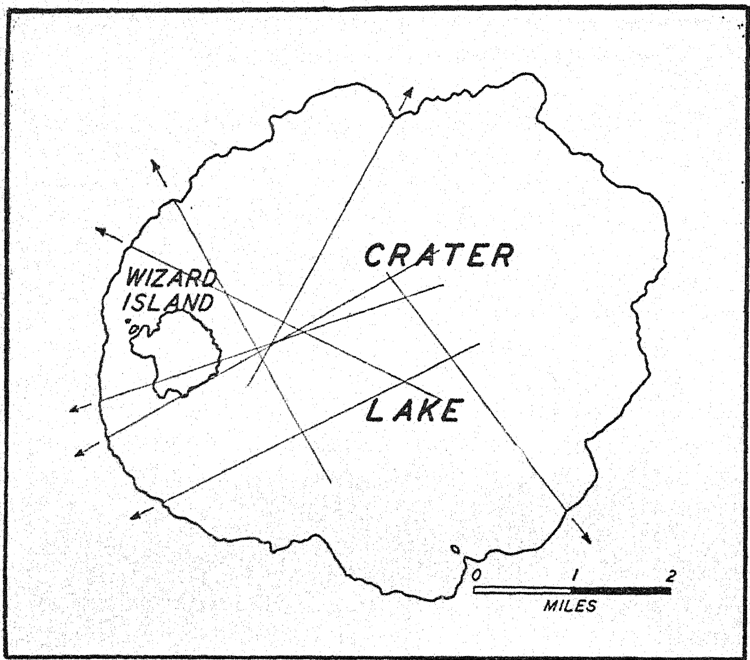


FIGURE 13.—The direction of ice movement during the early stages of glaciation on Mount Mazama. The projected striae suggest that the ice spread outward from a mountain, the central peak of which was somewhere above the middle of the present lake.

stages of glaciation (fig. 13). For example, the reading recorded at Pumice Point is 300 feet below the rim, and the one just south of the Devils Backbone is over 800 feet below the rim or 300 feet from the water's edge. While the number of striae readings are necessarily fewer than those available for more recent glacial stages, the results obtained from their projection may be of equally great interest. The projected striae roughly converge above the center of the lake, again suggesting a central position for the main peak of the mountain of Mount Mazama down whose slopes the early glaciers moved. No projected striae converge over Wizard Island. This indicates that

no secondary cone had come into existence when the early glaciers were present. Any more definite conclusions must await further study of the volcanic history of the region.

THE SIGNIFICANCE

A glacio-volcanic sequence similar to that so clearly recorded in the rocks surrounding Crater Lake has probably occurred in the history of Mount Rainier, Mount Hood, Mount Shasta, and other volcanoes of the Cascade Range, but the evidence is not visible. Although Mount Rainier is dormant at present, the glaciers on its slopes are always in danger of being destroyed by a renewed volcanic eruption. Thus, previous generations of glaciers may have been destroyed. If the summit of Mount Rainier were suddenly to disappear, leaving a giant caldera in the base of the mountain, many of the conditions observed today at Crater Lake would very probably be duplicated. The collapse of Mount Mazama opened a book for the geomorphologist which might otherwise have remained closed forever.

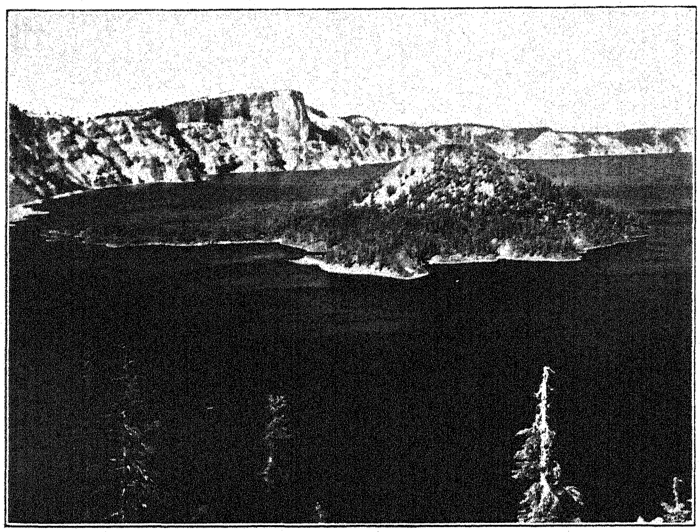
From the standpoint of the glaciologist and vulcanologist the results of the Crater Lake study are not limited in application to the Cascade Mountain region but apply to all volcanic areas where the summits rise to sufficient altitude to allow glaciers to form or where previous conditions have favored glaciation. Assuming that the stages in the growth of Mount Mazama preceding its collapse were normal for high volcanoes during the Pleistocene, we should expect to find similar glacio-volcanic sequences in many of the mountain regions throughout the world. Unfortunately, the records of other volcanoes are so completely hidden that a sequence comparable to that discovered at Crater Lake may never be available for study. Evidence of glacio-volcanic sequences may, however, be uncovered in the walls of the stream valleys which radiate from large volcanoes. It is very probable that the valleys which dissect the lower slopes of Mount Rainier hold records of this kind.

In addition to the light which Mazama's story may cast upon the history of other volcanoes, there is a still greater significance. Each glacial deposit exposed in the rim indicates that snow accumulated on the mountain and that ice fields developed of sufficient size to descend the slopes, polishing and deeply striating the rocks. The time required to accomplish this task is necessarily great, probably many thousand years. The four known glacial records interbedded with volcanic materials indicate four long intervals in the growth of Mount Mazama.

The development of a soil horizon like that at Pumice Point required much time. Each layer of volcanic breccia overlain by a

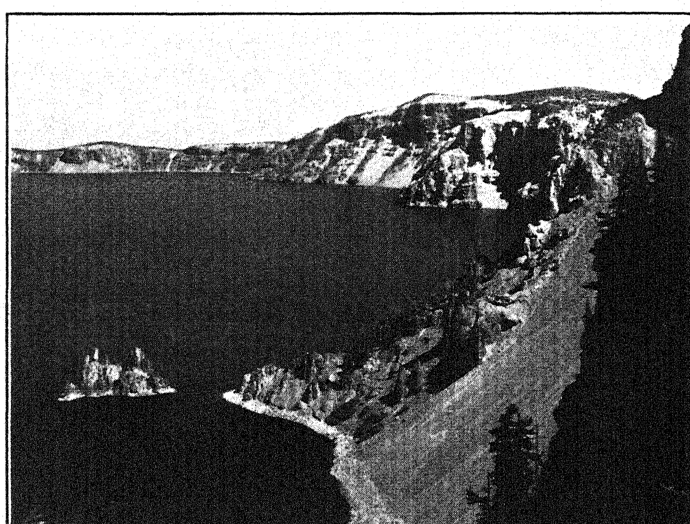
lava flow implies that the volcano changed from an explosive type to a quiet eruptive type. The occurrence of dacite instead of andesite during the late stages of mountain growth signifies internal changes. Each successive layer of volcanic material exposed in the rim required time to accumulate, and each one that was followed by glaciation required time to cool before the process of snow accumulation could start.

Thus the glacial record of an extinct volcano helps to establish time intervals in volcano-building and contributes to the knowledge of earth history.



1. WIZARD ISLAND AND THE WESTERN RIM.

The massive flow producing the high cliff beyond and to the left of Wizard Island is Llao Rock.



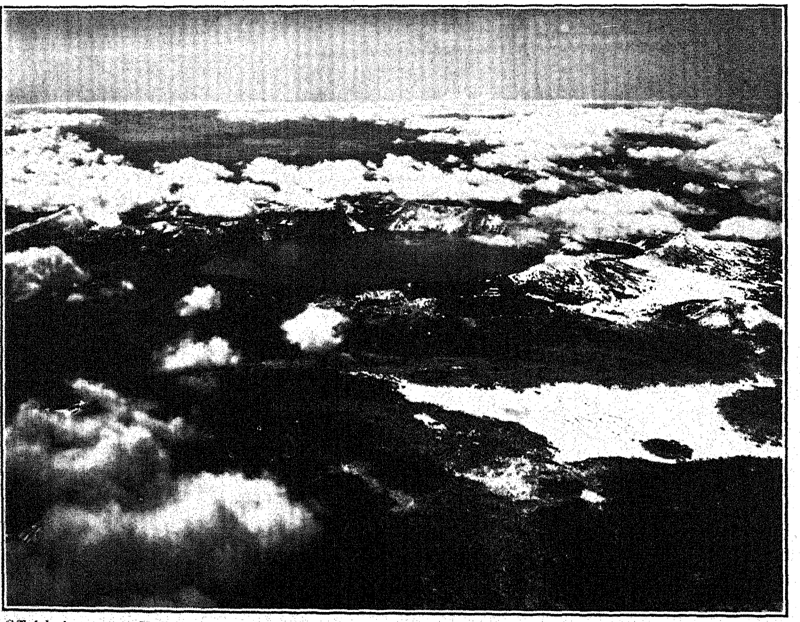
2. THE RUGGED EASTERN RIM WITH LARGE TALUS SLOPES REACHING THE WATER'S EDGE.

Phantom ship appears in the foreground.

Official photograph, U. S. Army Air Corps.

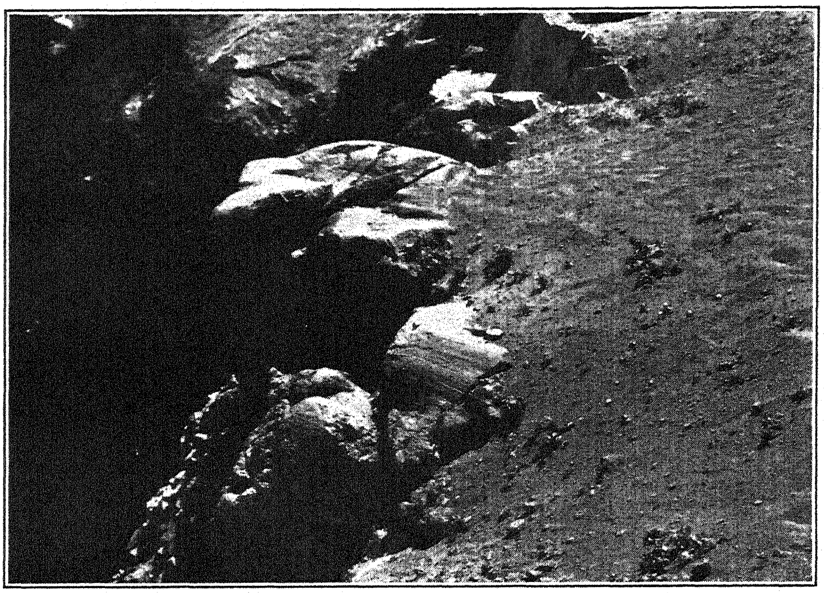
1. LOOKING SOUTHEAST FROM A POINT ABOVE AND TO THE WEST OF THE DEVILS BACKBONE.

The remarkable U-shaped valley of Sun Creek, visible in the photograph, is the result of glacial scour immediately preceding the collapse of Mount Mazama.

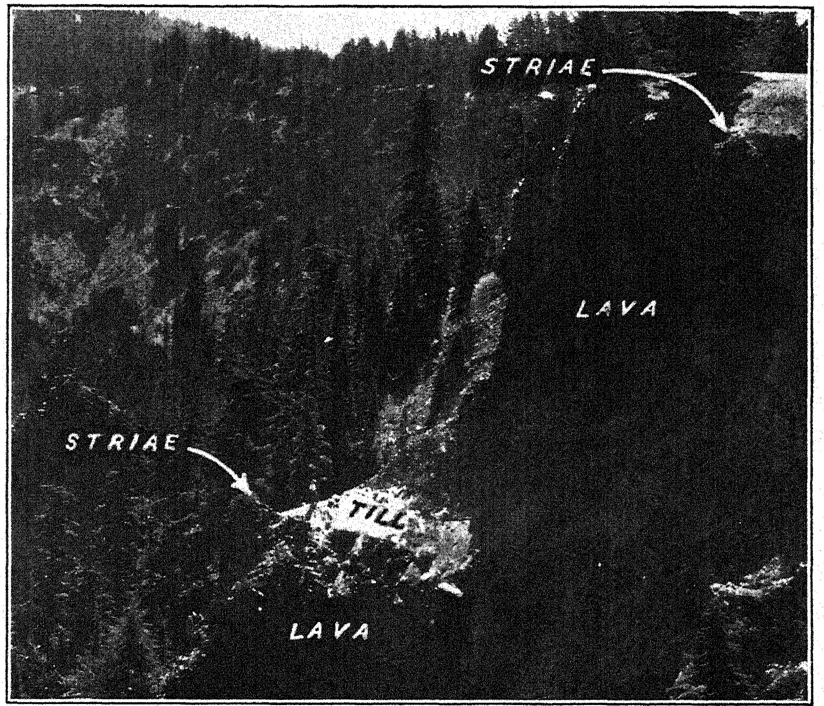


Official photograph, U. S. Army Air Corps.

2. CRATER LAKE FROM ABOVE THE CLOUDS.

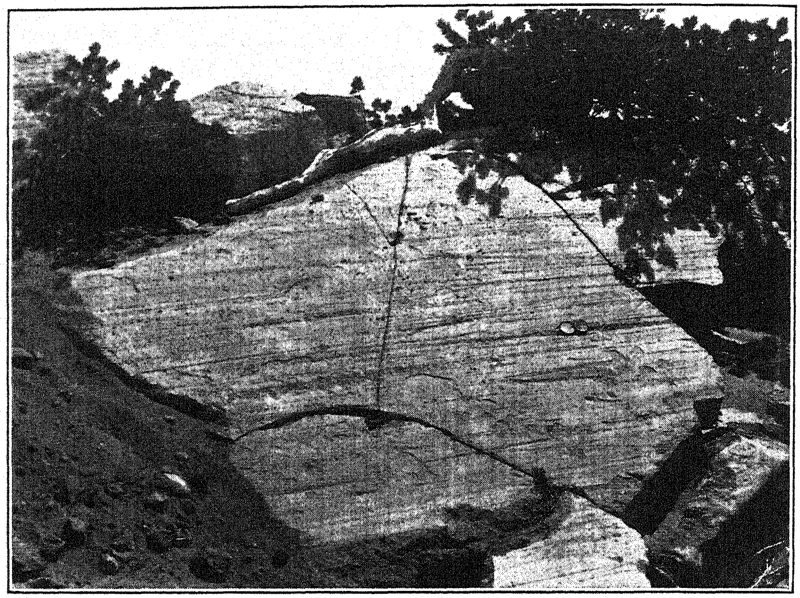


1. GLACIALLY STRIATED SURFACES AT THE EDGE OF THE RIM WEST OF DISCOVERY POINT.



2. THE TYPE LOCALITY AT DISCOVERY POINT.

The striated surface of figure 1 (above) occurs on the rim a few feet to the right of this photograph. The boulder till interbedded with the lavas indicates a stage of glaciation which was terminated by volcanic eruption.

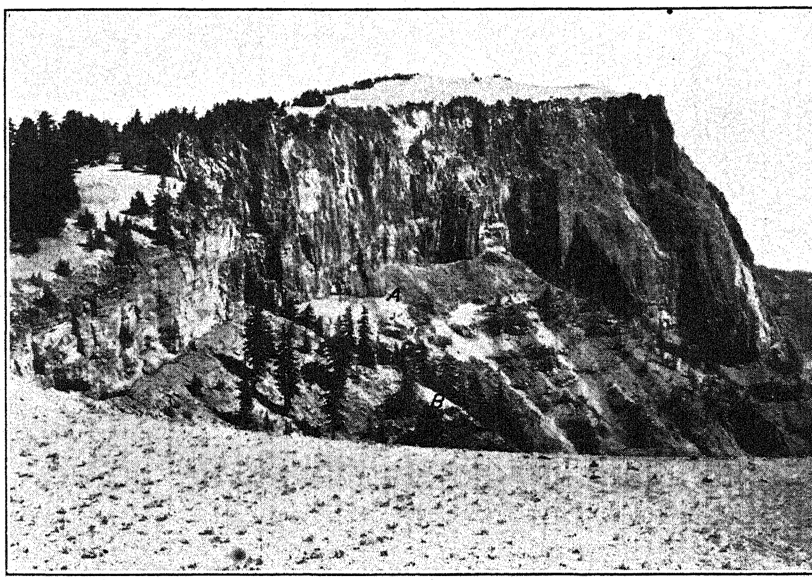


1. GLACIAL STRIAE ON THE LAVAS JUST NORTH OF THE DEVILS BACKBONE.

The surface is highly polished and, except where the rock has chipped, owing to weathering, the striae are very distinct. The ice moved in a N. 17° W. direction across this lava surface.

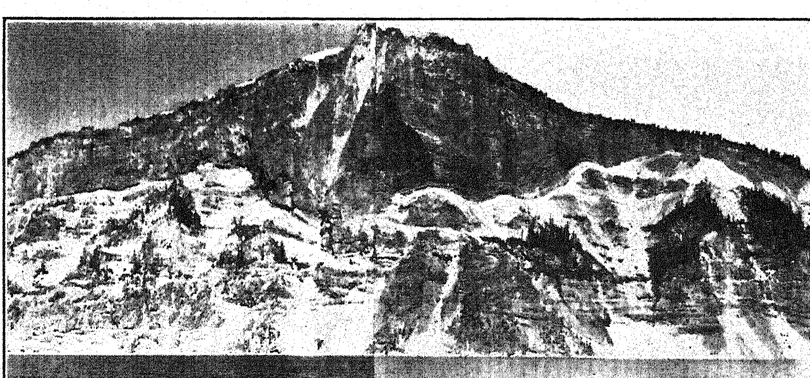
2. A MUCH WEATHERED, GLACIALLY-GROOVED SURFACE A SHORT DISTANCE SOUTH OF THE NORTH ENTRANCE RANGER STATION.

Although the age of the grooves is difficult to determine, they appear to be related to a stage of glaciation which ended with the return of volcanic action on the mountain.



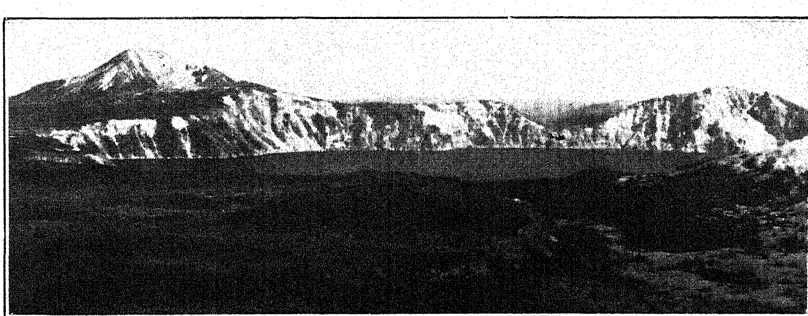
1. LLAO ROCK VIEWED FROM THE SOUTH.

Beneath the massive dacite flow at a point marked *A* is an exposure of glacial till. At *B* a similar deposit rests upon a striated surface. The contact between the lava and underlying till suggests that ice existed on the mountain during the first stages of the eruption which produced Llao Rock.



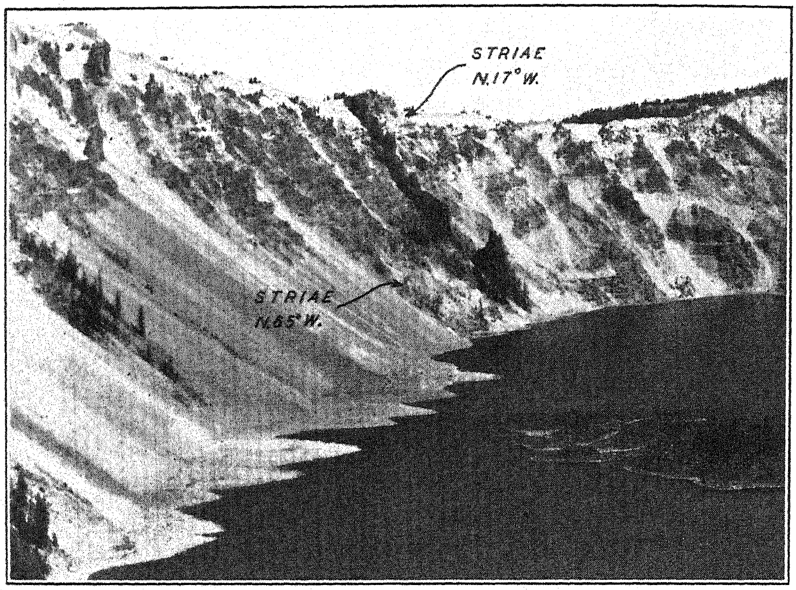
2. THE MASSIVE LLAO FLOW WHICH DESCENDED UPON A GLACIAL LANDSCAPE FILLING THE U-SHAPED VALLEYS AND BURYING THE MORAINIC DEBRIS.

The lower portion of the cliff which rises almost vertically from the water's edge is composed of alternating layers of lava and volcanic ejectamenta recording the growth of the young Mount Mazama.



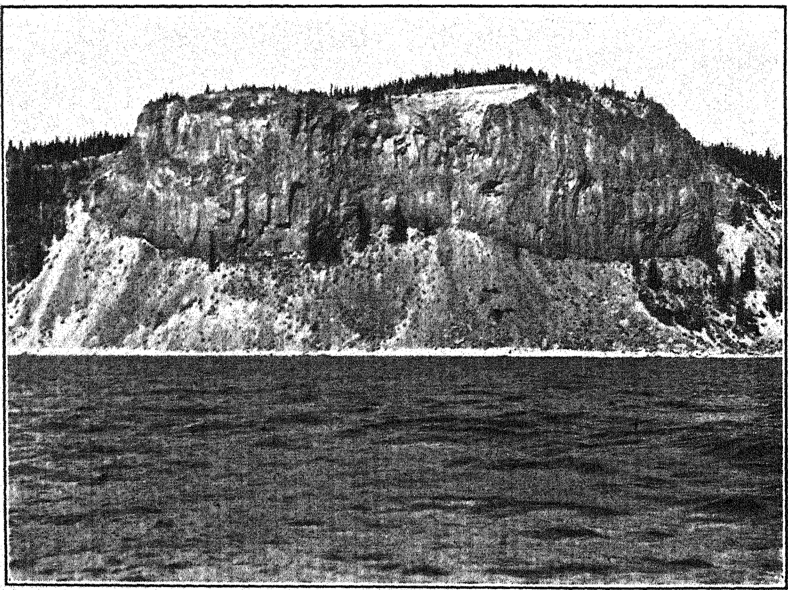
Official photograph, U. S. Army Air Corps.

3. CRATER LAKE VIEWED FROM THE NORTHWEST.



1. A PORTION OF THE RIM SHOWING THE LARGE BLACK DIKE KNOWN AS THE DEVILS BACKBONE.

The location of the oldest glacial record is indicated by the lower striae reading. The striae on the rim are those pictured in figure 1 of plate 4 and were produced by the last glaciers to descend the west slope of Mount Mazama.



2. THE PALISADES AS SEEN FROM THE LAKE.

Beneath the talus material is a glacial till containing many well striated boulders. The bottom of the deposit is presumably below the level of the lake.

CONCRETIONS—FREAKS IN STONE

By R. S. Bassler
Head Curator of Geology, United States National Museum

[With 3 plates]

Among the thousands of geologic specimens received for examination every year at the Smithsonian Institution, certain kinds occur very frequently. Among these are dark, heavy rocks mistaken for meteorites; pieces of clear rock crystal or quartz, believed to be diamonds; yellow iron pyrites, sulphide of iron, so often thought to be true gold as to merit its common name "fool's gold"; and supposed petrified animals which usually prove to be concretions, the subject of this paper. The last are probably the most mystifying, and it is difficult—indeed sometimes impossible—to convince the amateur collector that they are not what they seem, but simply aggregations of mineral matter which, through their method of formation, by chance assume the form of familiar objects.

In the living world nature runs true to form in reproducing animal and plant species after their own kind, but in the inanimate kingdom she often turns playful and generates most bizarre-looking objects. For example, in the realm of rocks and minerals, geometric figures of amazing regularity, specimens resembling living forms, and fantastic objects never seen elsewhere are found among these special rock formations, concretions, some of which are so unusual that they might truly be called "sports of nature." Many concretions assume such grotesque and marvelous shapes that it is no wonder they excite popular curiosity, and in some countries are believed to be of supernatural origin or are called fairy stones, and sometimes are even used as charms.

Stones, unendowed with life, do not grow like living things by inward accretion, but by external additions. Concretions are the stones that best show this method of growth, for they increase in size, layer by layer over their surfaces, finally forming variously and often very curiously shaped masses of firmly cemented mineral matter. They are found embedded sometimes in porous but often in very impervious rocks, or weathered out at the surface. Their

frequent occurrence and the interest they occasion bring them more attention than is warranted from the standpoint of the geologist, for to him they have little importance and rarely are rich enough in ore or mineral content to be of economic value. In general, concretions are more or less rounded or discoidal masses of solid material accumulated by condensation or segregation of similar mineral substances. They are sometimes rootlike or cylindrical in shape, or they may even resemble great logs of stone. In geology the term is usually restricted to the segregation in concentric layers of calcareous, siliceous, or clayey matter around some nucleus—a leaf, a shell, or a grain of sand—until there results a spherical or rounded, flattened mass, which may vary in size from a pin head to great balls of rock 10 feet or more in diameter. Single concretions are usually spherical, but some become flattened or much curved. Sometimes two or more concretions unite in the course of their growth, and again a new concretion may start on the surface of an older one, enlarging layer by layer. This latter type often results in the curious animal-like objects. These are easily understood if studied in connection with associated examples which show that simple rounded nodules with additional layers of growth developing about them grade into the more complicated specimens in which these extra layers have formed in rather symmetrically arranged lobes (pl. 1, figs. 1 to 5, 14). When extra layers are arranged more or less laterally, curious emblematic objects may result (pl. 1, figs. 11 to 13). If a shell serves as a nucleus, its whorls may be so covered that a so-called "fossil peanut" results (pl. 1, figs. 6 to 8).

Although concretions can be formed by physical means, as, for example, the rounding and enlargement of mud balls, or by organic means, whereby layer after layer of lime is precipitated around some nucleus by the action of plant growth in streams rich in lime, the majority owe their origin to concentration through chemical action, either as precipitates formed while the enclosing rock is being deposited, or as aggregates in the rock after deposition. Porous rock formations permitting the migration of mineral-bearing solutions allow the formation of concretions by the last method through cementation, long after the deposition of the enclosing rock. Thus, most of the concretions so common in the glacial clays of the Northern States have resulted from the concentration of small amounts of calcium carbonate scattered throughout the clay, with circulating ground water acting as the transporting agency.

Concretions containing well-preserved fossils were obviously formed at the same time as the enclosing rock, since otherwise the fossils would be at least partially destroyed. The fossils in such concretions are seldom flattened by the pressure of the overlying

strata, while those in the surrounding strata may be crushed by this weight. For this reason solid concretions occurring in shaly beds, such as those in the Cretaceous shales of the Great Plains, yield excellent fossils.

Certain concretions displace the rocks in which they are contained, indicating that they were formed after the deposition of the enclosing rock, pushing aside the rock in the course of their growth. Such curvature of the enclosing rock formation occurs most frequently in shales and is absent in sandstones, giving rise to another possible explanation, namely, that the shale beds may have settled around the concretion. Another method of formation is shown in the case of siliceous concretions exposed when limestone wears away. Here, it may be observed that as the limestone was dissolved by surface waters, the siliceous impurities segregated into nodules which were left at the surface or along water channels in the characteristic globular forms.

Deep-sea dredging in the red clays of the ocean depths often brings up concretions in the form of nodules of manganese dioxide. Colloidal silica, the gelatinous form, is, next to calcium carbonate, the most abundant of the soluble substances carried to the sea by the rivers. However, sea water contains but a very small percentage of silica, and therefore the large amount of gelatinous silica must have been deposited upon the ocean bottom. Here it assumes the nodular form by segregation, and concretions are the result. Such conditions of sedimentation occur over great stretches of sea bottom, so that today, as well as in the past, concretions occur usually in definite beds that can be traced over many miles. Thus, they can be used for correlating strata of the same age over wide areas.

Concretions are commonly composed of a single mineral, but frequently other substances occur as impurities. Calcium carbonate, silica, iron oxide, hydroxide, carbonate, or sulphide are the most common component materials. Clay stones and the calcareous concretions in shales and sandstones are composed largely of calcite, as are the concretions so abundant in the loess and the glacial clays widespread over the northern United States. To these latter forms the Germans have applied the name "Loesspüppchen", or "loess dolls" (pl. 1, fig. 4). Ironstone concretions are most common in sandstones and consist largely of quartz grains cemented by the oxide or hydroxide of iron. Such concretions may be collected in modern lakes and, indeed, are forming today in certain soils. Concretions of pyrite occur in dark shales containing organic matter, sometimes in sufficient abundance to constitute a source for this ore. Barite, or heavy spar, forms the beautiful concretions known as "petrified roses", in sediments accumulated under arid conditions.

Sandstone produces the largest concretions, as, for example, the loglike structures from South Dakota reaching a length of a hundred feet, and on the Great Plains the many cannonball forms, up to 12 feet in diameter, which lend a characteristic aspect to the scenery and, indeed, give rise to local names such as the Cannon Ball River.

Concretions are responsible for the curious structures known as "Septaria", so named from the partitions (septa) traversing them. A clay concretion in the process of its formation will shrink as the mud dries and hardens, and fractures radiating from the center, often very regularly arranged, will ensue (pl. 1, figs. 9, 10). While the filling of such shrinkage cracks with mineral matter is undoubtedly the cause of the septaria, the exact process is not understood. Probably a concretion with a colloidal or gelatinous clay center changes to a crystalline solid with accompanying contraction and cracking; or possibly the expulsion of water from the saturated central area produces the same result. The open spaces caused by these fractures are later usually filled with some mineral matter other than that forming the nodule (pl. 2, fig. 1). Should this be more insoluble than the material of the original concretion, it will stand out as ridged polygons when the nodule is subjected to weathering. Or, should the more soluble concretion be entirely dissolved away, a curious framework of the mineral-filled fractures remains (pl. 2, fig. 2). Septaria are particularly interesting to the mineral collector, for the veins filling the fractures may yield crystals of a variety of minerals, ranging from the metallic sulphides to the nonmetallics such as barite and selenite. Certain very abundant small bodies termed pisolites and oolites have a concretionary structure, but their origin is somewhat different.

A third type of concretion closely resembling septaria externally presents a most artistic appearance because the surface is ornamented with large and small polygons arranged in a geometric design. Possibly such concretions (pl. 3, figs. 1, 2) were, like septaria, formed by filling of shrinkage cracks, but they now show no evidence of such an origin, for the polygonal marking is apparent only at the surface. When the surface is smoothed by abrasion, only the solid dense mineral is visible. The excellent example of this type here figured came from some Cretaceous formation along the Cannon Ball River of North Dakota, and was presented to the Smithsonian Institution by Percy Train. The exterior of this concretion is of limonite, iron hydroxide, but the interior, according to Mr. Train, consists of hematite radiating from a rounded water-worn boulder that served as a nucleus, which in one instance was one-third the size of the specimen. Inspection of plate 3 will show that the upper surface of the

entire sphere is divided into seven or more large polygonal areas, each of which is subdivided into about the same number of polygons containing a central region of minute polygons surrounded by a smooth area. This central region exhibits the same arrangement of polygonal areas as the entire sphere and perhaps further subdivisions were continued on a microscopic scale in the smallest polygons. Additional specimens of this type of concretion, if available for study, would undoubtedly show the various stages of growth and explain the origin of this interesting type.

Concretions are of economic value as a source of minerals or ores as well as of well-preserved fossils. The calcareous concretions so abundant in the London clay of southeastern England have been much used in the making of cement. Similarly, clay ironstone nodules, termed sphaerosiderites, have been a prolific source of iron ore in various countries. As a source of well-preserved fossils these nodules are supreme, and the splitting open of concretions is a favorite sport of the geologist. Sometimes the concretion has formed about a considerable cluster of fossils, but more often only one of many nodules reveals recognizable remains of an animal or plant. Hence, the possibility of discovery of a fossilized complete fish (pl. 2), a spider, a crustacean, or a leaf (pl. 3) provides an element of chance that adds greatly to the interest of collecting.

Many valleys of the northern United States where the glacial clays are so prevalent, such as that of the Hudson River, have afforded innumerable specimens, no one precisely like another. The bands of flint concretions lying parallel with the chalk strata in the chalk cliffs of England are so conspicuous that they are known to every traveler. The Tertiary sands and clay formations of our Great Plains, as noted before, comprise layers sometimes crowded with enormous spherical forms. Here, too, the concretions often are so abundant as to strengthen the loose sands and clays sufficiently to form a resistant bed which may stand up as a cliff along a stream. The Upper Paleozoic black shales of New York, Ontario, and Ohio often contain large interbedded concretions that have formed about dismembered bones and plates of gigantic fossil fishes described from these areas. Perhaps the most interesting locality of all to the paleontologist is along Mazon Creek in Grundy County, Ill., where animal and plant remains of many varied types serve as nuclei for the clay-ironstone nodules occurring in the Coal Measures. Fern leaves exquisitely preserved (pl. 3, fig. 3) and in a great variety of forms are the most abundant fossils here, but primitive cockroaches of gigantic size, very ancient horseshoe crabs (pl. 2, fig. 4), and even early forms of fish (pl. 2, fig. 3) sometimes reward and delight the lucky collector.

DESCRIPTION OF PLATES

(Illustrations slightly reduced in size)

PLATE 1

FIGURES 1–5. A series of clay lime concretions from the glacial clays of Schoharie Creek, N. Y., and Barry's Bay, Ontario, showing the evolution from the simple type to the loesspüppchen (fig. 4) and the animal forms (fig. 5).

FIGURES 6–8. Petrified "peanuts" showing formation from fresh-water shells coated layer after layer with lime (6) until their original outlines are lost (8).

FIGURES 9, 10. Mud concretion of present day origin from the Illinois bank of the Mississippi River. The fractured interior suggests the origin of septaria.

FIGURES 11–13. Clay lime concretions from glacial clays of Vermont exhibiting three phases in the formation of the emblematic forms.

FIGURE 14. A specimen from Texas, supposed to represent a fossil turtle.

PLATE 2

FIGURE 1. A clay lime septarium, ½ natural size, from the Devonian rocks of western New York, with the shrinkage cracks filled with crystalline calcium carbonate. The original polygons of large size are in process of subdivision into smaller areas by secondary shrinkage.

FIGURE 2. A siliceous pseudomorph resulting from the solution of a septarium; about ½ natural size. Calcareous septa in the original septarium were replaced by silica which because of its little solubility in water was left behind when the substance of the nodule itself was dissolved away. From fuller's earth deposit at Groveton, Ga.

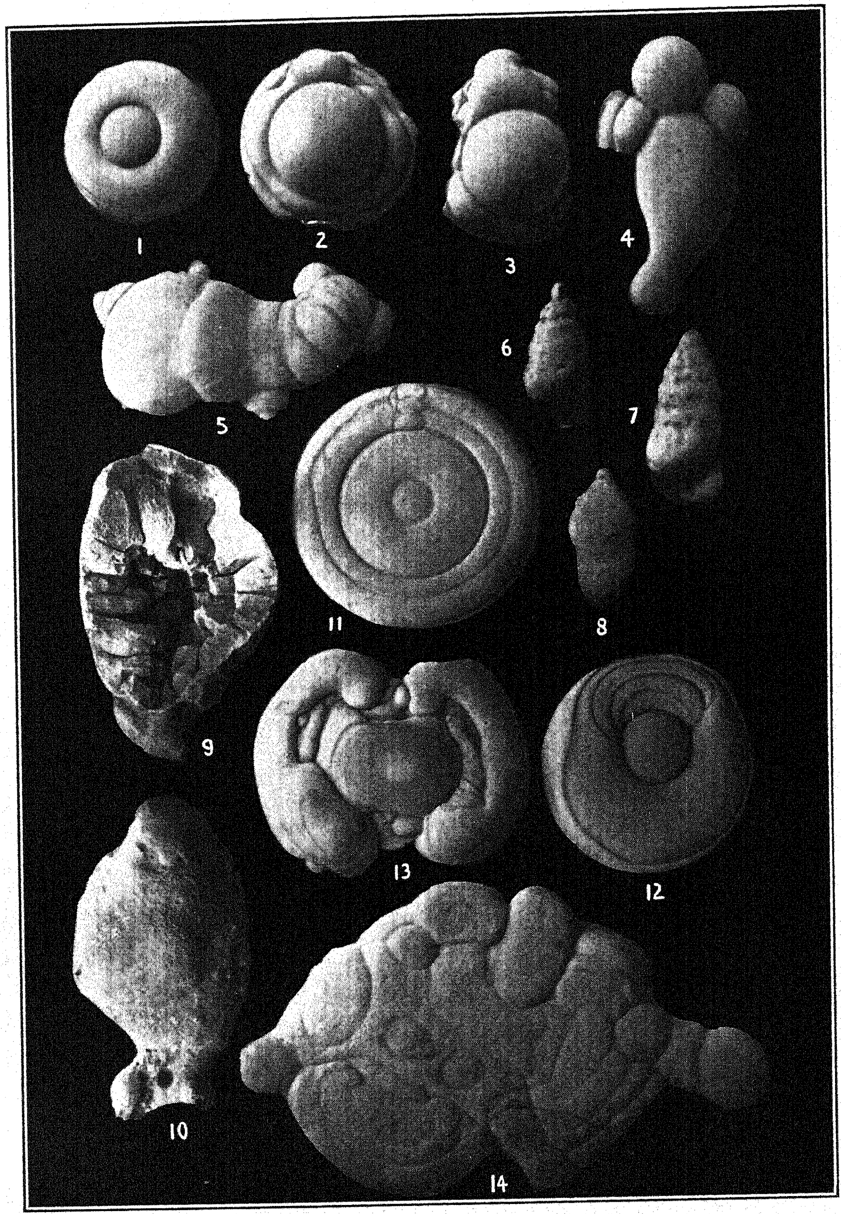
FIGURE 3. A primitive ganoid fish forming the nucleus of a clay ironstone concretion from Mazon Creek, Ill. Slightly enlarged.

FIGURE 4. An ironstone nodule from Mazon Creek which when split in half exhibited a fossil horseshoe crab.

PLATE 3

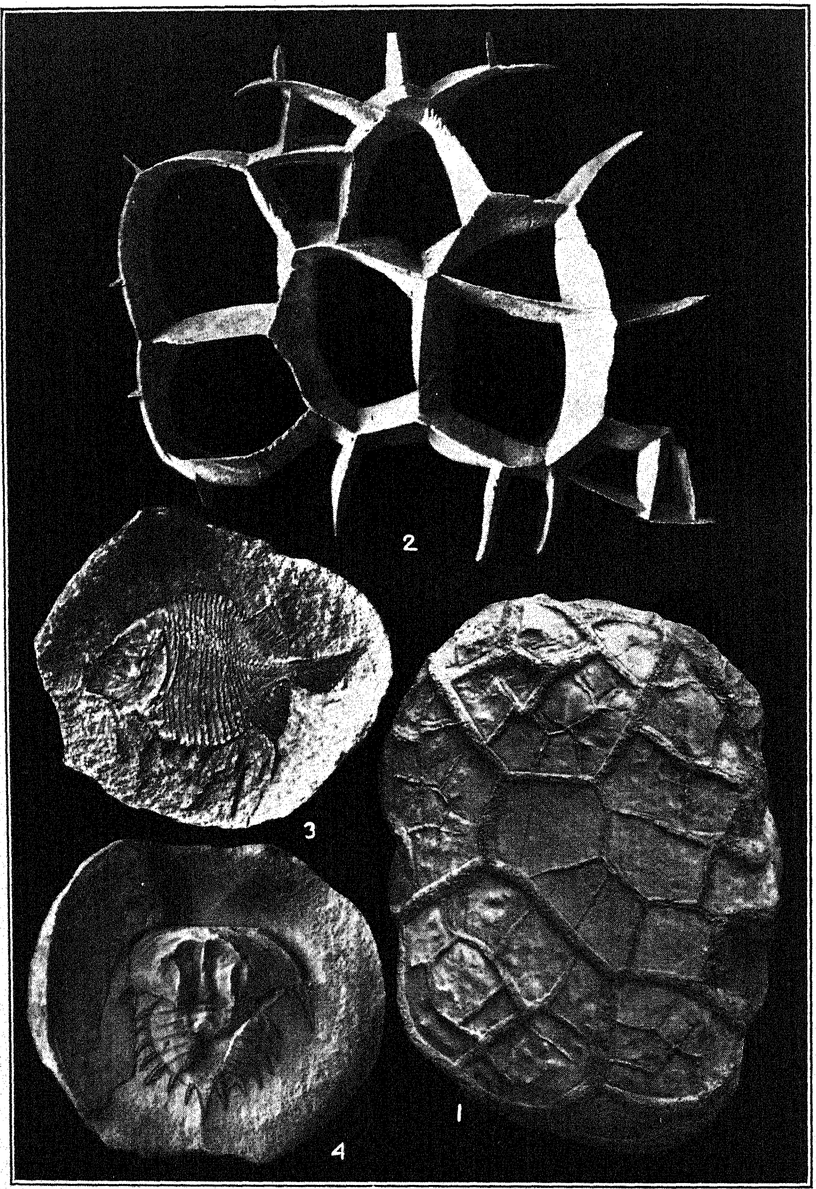
FIGURES 1, 2. A concretion of iron hydroxide, slightly less than natural size, and a portion enlarged, showing the regular arrangement of the markings of the first, second, and third order. Cannon Ball River of North Dakota.

FIGURE 3. Ironstone concretion from Mazon Creek, Ill., split along the line of the seed fern frond which served as a nucleus.



CONCRETIONS.

(For description, see p. 326.)



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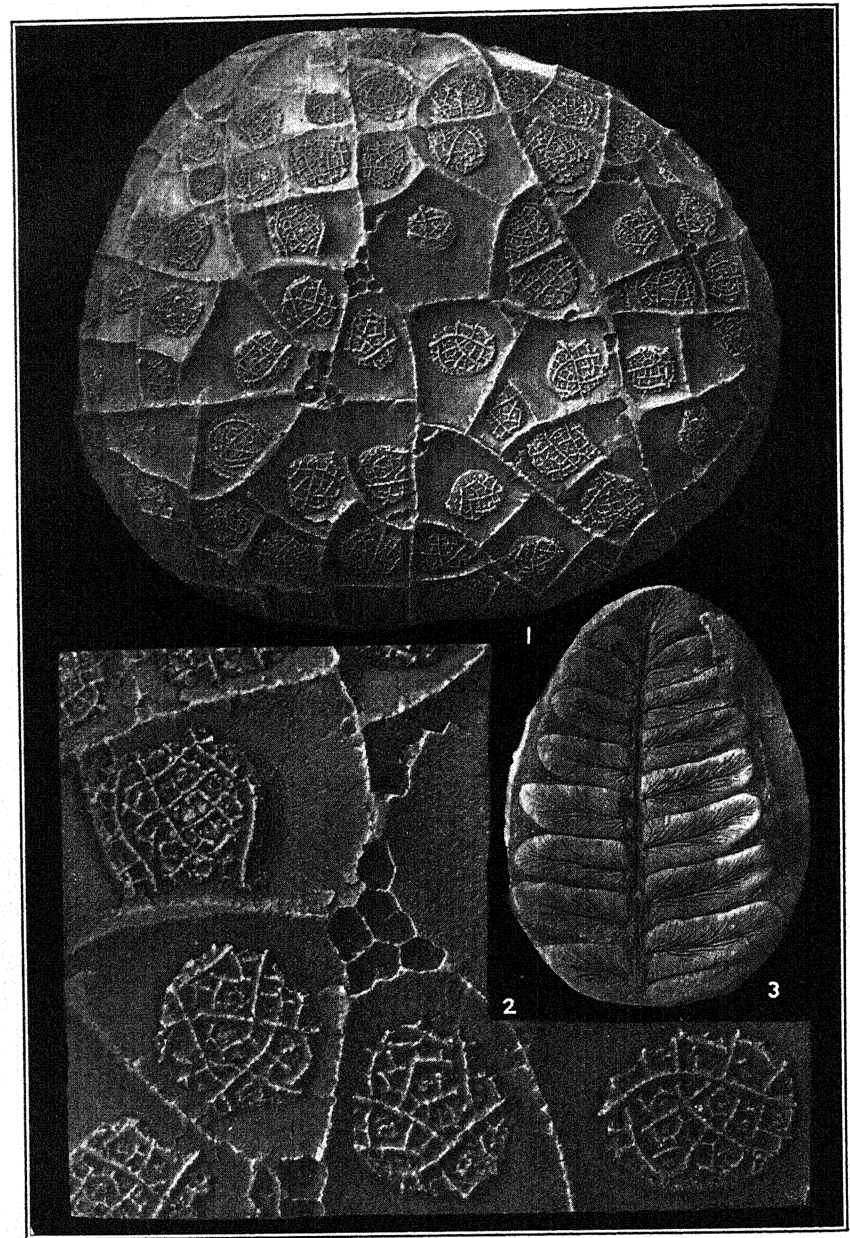

CONCRETIONS.

(For description, see p. 326.)

BIOLOGY AND HUMAN TRENDS[1]

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I

To discuss adequately in a brief address the assigned subject, Biology and the Social Consequences of Its Advances, is plainly a large order, and one beset with considerable difficulties. For on the one hand biology as a science is still largely in the descriptive and historical phase of its development, and sociology is even more so, with the consequence that an account of the significant achievements of these sciences cannot be expressed in the concise and rational shorthand that is so useful in physics; and, on the other hand, to appraise the theoretical consequences of scientific discoveries implies a certain skill in the dangerous art of prophecy. Not having any noteworthy aptitude as a prophet I can only put before you, in all modesty, the views of one biologist about some of the more evident relations between certain well-established biological facts and principles and some of the more characteristic features of the collective behavior of mankind. While I cannot speak with officially sanctioned authority for more than one particular biologist, it does seem absolutely certain that just in proportion as any of the sciences, including biology, succeed in their effort to establish sound general principles and laws, just in that proportion will their advances be inevitably reflected in collective human behavior. The thoughts and actions of all mankind were permanently and irreversibly altered from what they were before, after the Origin of Species had been published in 1859. A corresponding alteration, more or less significant as the case may be, occurs whenever a real discovery in science is made or a sound generalization established.

II

In the great Symphony of Life there appear to be three, and only three, main, basic biological themes, out of which come all the pleasant or harsh, useful or harmful, simple or complex counter-melodies,

[1] Reprinted by permission from Journal of The Washington Academy of Sciences, vol. 25, no. 6, June 15, 1935.

harmonies, and dissonances of the business of living. These main basic themes are:

First: The urge to individual personal *survival* here and now. This appears to be an attribute of all living matter.

Second: The urge to *reproduction* which again appears to be a property of all that lives.

Third: *Variability*, once more common to all living matter, in both its genetic and somatic aspects, the one leading to the observed differences or variations between individual organisms, the other embodying the differences in the same individual at different times in its life.

Finally, it is to be remembered that it is impossible to discuss or even to imagine life or living things without taking into account the rest of the universe in which they exist. So then we must add to our material for discussion one more item that corresponds roughly to the fiddles, flutes, horns, printed music, desks, and other impedimenta not musical per se but without which a symphony would never reach the ears. This item is:

Fourth: The environment that conditions and in some degree determines all vital phenomena.

Let us now examine each of these four items in some detail.

The urge to survival [2] may fairly be regarded as the most fundamental attribute of living things and is therefore placed first in the list. It may be well to point out at the start that in its essence this urge to survival is rather completely and uncompromisingly selfish. To the best of its ability the individual organism so conducts its affairs as to continue living just as long as possible, regardless of what other organisms may do or think about it. When extinction threatens every resource is brought to bear to fend it off. Basically this is what underlies the struggle for existence. Out of it, associated with it, and because of it come great ranges of biological phenomena that we have, for combined reasons of convenience and pedantry, departmentalized: such as food getting, metabolism, and nutrition, cellular and humoral defense mechanisms furnishing immunity and resistance to disease, protective shelter seeking and building, natural selection, and in good part evolution itself.

As a matter of observed fact this survival urge is primal and deeply rooted. Whenever and wherever we see its fundamental selfishness apparently in abeyance or even much abated, and seemingly replaced

[2] There are curious aspects to this universal urge to individual survival. One of them is the biological uselessness of much of it. It would be extremely difficult, if not impossible, to find any rational biological purpose served by the survival of the individual after it has reproduced itself. Yet in not a few organisms, including man, there is normally a considerable part of the life span lived after adequate reproduction has been accomplished. Living grandparents, great-grandparents, and celibate clergymen are among Nature's gaudier examples of Thorstein Veblen's "conspicuous waste" in the realm of pure biology.

by altruism or "mutual aid" as it has been called, we may be sure, I think, that one or the other of two things has happened. Either, as among the invertebrates (especially the social insects) and the lower vertebrates, the "mutual aid" is not individually motivated but is a mechanistic group consequence of caste differentiation and integration, with no more (and no less) of an altruistic element in it than there is in the cellular differentiation and integration in the embryonic development of the individual; or, as in man and to some extent among his nearest relatives, complex psychological elements have been added to the picture in the course of evolution, which may seem at times to overwhelm and obliterate the more primitive and deeply rooted biological urge. The most obvious of these added factors amounts really to a more enlightened self-interest—that is to say, a belief that for the present and until times get much worse it will be likely to conduce more effectively to individual survival to play along with and help one's neighbors in the crowd.

This statement is, from the necessity of brevity, much too bald and apparently dogmatic in its form and wants more explanatory elucidation and development than we shall have time to give it. But I think it essentially conforms to at least a part of the reality. It is reasonable to suppose that the individual soldier ant is unaware of the fact that its activities and efforts are of benefit to the social group (the colony) to which it belongs. On the contrary, it seems likely that when it fights it does so because it is its inherent and entailed nature so to do. In fighting it is expressing its own will to live or urge to survival, and in the only way of which it is capable. On the human side, in thinking of the personal motivation of altruistic behavior I am always reminded of a speech of Brotteaux in Les Dieux ont Soif, perhaps the greatest novel Anatole France ever wrote. It is (I quote from Allinson's translation):

> What I am doing now, the merit of which you exaggerate, is not done for any love of you, for indeed, albeit you are a lovable man, * * *, I know you too little to love you. Nor yet do I act so for love of humanity; for I am not so simple as to think * * * that humanity has rights. * * * I do it out of that selfishness which inspires mankind to perform all their deeds of generosity and self-sacrifice, by making them recognize themselves in all who are unfortunate, by disposing them to commiserate their own calamities in the calamities of others and by inciting them to offer help to a mortal resembling themselves in nature and destiny, so that they think they are succoring themselves in succoring him.

Man's behavior, and particularly his social behavior, is motivated by so complex a set of physiological and psychological factors, appetites, emotions, and reasons, as to be extremely difficult to disentangle in a particular instance. But it may safely be said that whenever he curbs his primal urge to personal survival, he does it for

secondary reasons superimposed upon his natural, protoplasmic will-to-live. Many of these reasons are, collectively, what we call social. They represent purposeful adaptations in what Wheeler has convincingly argued is the next emergent level above the individual organismal. In most human beings these secondary social adaptations of behavior are still somewhat incomplete and imperfect, as clearly appears in times of great stress or danger. And the extent to which the highest forms of human altruistic social adaptations have real and enduring survival value, has yet to be measured. It can be argued with some plausibility that why they give the appearance of having some survival value, or at least of not being positively harmful, is because they became even moderately widespread only during that recent portion of human history in which living has been relatively easy for all mankind. It has been relatively easy for two reasons: Low density of population, in general; and rapidly increasing knowledge of applied science with its accompanying industrial developments. In a world where getting a living was easy, altruistic social relations were correspondingly easy. Instances, and localities of a real struggle for existence between individual men (other than during large-caliber wars or in the processes incident to the assumption of the "white man's burden") have been rare in this world since the beginning of the nineteenth century. And few have ever seriously alleged that war is an altruistic enterprise; nor is it at all uncertain that the pleasures of "civilizing" backward peoples are, like those of condescension, singularly one-sided.

The urge to reproduce is second in power, if at all, only to that for survival. This basic attribute of living material, like the other, includes in its scope great ranges of academically labeled and pigeonholed biological phenomena—of which among the more important are perhaps population growth with its part in the struggle for existence and natural selection; and heredity with its concomitants of development and growth. For heredity is most clearly to be apprehended as an aspect of reproduction. Living things do not merely reproduce; they reproduce *themselves*. This fact makes it clear that, philosophically viewed, the urge to reproduction is really a part—an extension if you like—of the primal urge to survival. If the individual cannot ensure his own indefinite earthly immortality he can and does try his very best to see that his stirp shall keep on living forever and ever. Naturally this self-reproductive process tends toward social as well as biological stability.

Genes are almost incredibly stable and resistant to alteration in the natural and usual circumstances of life. For something over 15 years there has been going on in my laboratory a continuous experi-

ment designed to test this point in a simple and direct way. To-night I make the first public statement about it. This experiment has now included over 300 successive generations—perhaps the longest bit of controlled breeding ever carried out, with the results in each successive generation carefully observed and precisely recorded. Allowing 30 years as a round figure for the average duration of a human generation the time equivalent in human reproduction of this experiment would be of the order of 9,000 years—considerably longer than the total span of man's even dimly recorded history. The objective of this experiment with *Drosophila* has been to see whether a simple Mendelian ratio involving but one character would or could be altered in the passage of time by such natural forces as selection, different systems of breeding (such, for example, as that called "grading up" by livestock breeders), and wide alterations of the environment nearly up to the limits of the organism's ability to go on living at all. The plan of the experiment is a simple one. It started by crossing a normal fruit fly (*Drosophila melanogaster*) possessing the normal wings characteristic of the species, with the pure mutant form *Vestigial*, so-called because the wings are reduced to nonfunctional vestiges. This wing characteristic is associated with a single gene. In the next generation all the flies produced by the pair with which we started had normal standard wings, normal being dominant to vestigial. These flies of the first cross-bred generation were then mated to pure vestigials (back-crossed to the recessive parent, in technical genetic language) to produce the second cross-bred generation. Of the offspring of these matings approximately one-half had normal wings, because they carried the original normal wing gene, and the other half had vestigial wings, all this being in accord with regular Mendelian expectation. The vestigial-winged flies of this and all later generations were killed and thrown away as soon as they had emerged and been counted. The normal winged flies were again mated to pure vestigials to produce the next generation. And so on with undeviating regularity for more than 300 generations. What the plan means in briefest terms is that since the rather stupendously long time (measured in generations) when the experiment began the only hereditary determiner (gene) for normal wings that has ever been in the system is the one that was contributed by the one single normal wild type fly with which we started. All the normal winged flies now appearing in the populations of the successive generations of the experiment have normal wings only because their Urgrossvater had them 300 generations ago, and for no other reason.

The net result of the experiment has been to show that the gene involved has preserved its initial characteristics unaltered. So also

has the cellular mechanism for the shuffling and sorting of the genes in each generation. The approximately 50–50 ratio of normal winged to vestigial winged flies appears generation after generation with somewhat wearisome regularity. The demonstration of the inherent stability of the genic mechanism of heredity that this experiment has given is extremely impressive.

Analogous phenomena of organic stability are observed in nature. There are considerable numbers of firmly established instances of organisms living today that are specifically identical with their progenitors in earlier geological eras. Among the Foraminifera 1 species (*Lagena sulcata*) has persisted unchanged from Silurian times down to the present; 1 species (*Globigerina bulloides*) from the Devonian to the present; 2 species from the Carboniferous; 2 from the Permian; 4 from the Triassic; 7 from the Jurassic; and 15 from the Cretaceous. The significance of these cases cannot be overemphasized. When it is comprehended that organisms now living have not changed by a perceptible amount from what they were millions upon millions of years ago in Paleozoic times in those minutiae of structure upon which systematists base their specific distinctions and descriptions, the conservatism and stability of nature begin to be realized.

In human biology the conservative and stable element of true biological heredity is supplemented and reinforced by what has been variously called "social heredity", or tradition, or the mores of the group to which the individual and his stirp belong. This is, of course, not inheritance at all in a proper biological sense. It is rather an environmental matter at bottom. A born Englishman transported to America as a child may, and in fact usually does, come as a man to think and act like an American. But to make him do this if he lives his whole life in England among the people of his kind would be virtually impossible. And it is a matter of statistical fact that vastly more human beings live out their lives not far from where they were born and among their kind of people than migrate or are transplanted into realms of other traditions and mores. In consequence "social inheritance" or tradition plays an enormous but usually underestimated part in determining the individual and collective behavior of human beings. Its effects have not infrequently been confused with those of true biological heredity. Masses of data have been collected to show that near relatives, particularly fathers and sons, frequently follow the same professions or callings. It is often quite erroneously concluded that such facts prove a biological inheritance of talent or ability, either in general, or for a particular calling, or both. Such data are inherently incapable of proving any such a conclusion. The observations can be

much more simply and satisfactorily accounted for in the main by the operation of the purely environmental factors of familiar contact from childhood, training, easy opportunity of entrance, and the social pressure of tradition; in short, by "social", not biological, inheritance.

Our third unique and universal biological principle, variability, has two aspects, as has already been pointed out. No two living organisms are exactly like each other in all particulars, and no single organism is precisely the same at any two moments in its lifetime. The first of these aspects is the only one that is conventionally called variability. It is mainly caused by the combined interaction of genetic shufflings and recombinations and the environment. The second aspect of organic variability is usually and conveniently called adaptability. It is an odd and remarkable phenomenon. The unique thing is not that organisms are more or less fitted or adapted to the circumstances in which they find themselves. Inanimate objects of various sorts, and particularly that category of them that we call machines, are this. It is true that the adaptations of organisms and machines are brought about in different ways. But the fact of adaptation is present, and in principle identical, in both. We are, however, not concerned here with adaptation, but with self-started and self-controlled adaptability, which organisms have and machines do not. Organisms incessantly change and alter themselves to meet the fleeting changes in their circumstances. No living organism ever stays put. When it does it is dead, and in dying has passed into a wholly different category of matter.

The process goes even deeper than change and adaptability in behavior. The very material substance itself that makes up the living organism is constantly changing. What, then, does "personal identity" connote? What we are pleased to call the same identical man at the age of 70 years is composed of extremely little, if any, of the same material substance that made him up when he was 20 years old. Probably there is not a single molecule in him at 70 that was there at 20. In the intervening years the only thing about him that has survived is his pattern, a sort of transcendental or spiritual wraith through which has flowed a steady stream of matter and energy. There is a profound truth embodied in Cuvier's old comparison of a living organism to a whirlpool. It is the pattern that is the essence of the business. It alone endures. And it is constantly altering and adapting itself to changing circumstances. Especially is this true and important of the psychological panel of the total pattern of the human organism. It is this aspect of adaptability, the capacity of organisms for change ending only with death, that seems to be more important in its social consequences than its teleological aspect, if

indeed we are prepared to admit the reality of the latter at all, as some are not.

We may conclude this hasty survey of basic principles with a word or two about the environment. The effective environment of any particular living organism is determined by the pattern of that organism, just as truly as the pattern of the organism is in part at least determined by the environment. For a particular man, and for a group of similar men, but not for any mouse, the relative honesty of his banker and the urbanity of his dean are highly important elements in the effective environment. And what makes them so is not the bankishness of the banker nor the deanishness of the dean, but the pattern of the particular man of whom we are speaking—a pattern not shared by the mouse. In short the relation between organism and environment is everywhere and always mutually reciprocal and as man is the most complicated and manifoldly diverse in his capabilities of all organisms, so also is his effective environment the most complicated.

More extensively and more effectively than any other organism he makes his own environment. He is constantly altering it in the hope of making it better. But such is the interplay of the contradictory biological elements in his nature that he dislikes and resists any alteration of his environment by anyone else than himself or the group of people similar to himself to which he belongs. The social and political consequences of these opposing attitudes are far-reaching and encompass within their range the greater part of our communal troubles in this imperfect world.

The full implications of the reciprocally determinative influences of organism and environment seem to me to have been generally somewhat less than adequately valued in the last century's development of biological thought, and certainly an extremely inadequate amount of first-rate research has been put upon the matter. This is partly an obvious consequence of the trend given to biological philosophy by Darwin, Galton, Weismann, and Mendel, with their emphasis upon the entailed or endowed element in the whole biological picture. In human biology particularly the role played by heredity has come to take on many of the aspects of religious dogma. Indeed it has been urged that eugenics should be overtly espoused and developed as a religion. And all this has been going on in a world where consciously planned and directed alterations of environmental conditions have had far-reaching and profound biological effects upon whole populations, not alone in the field of public health but in many others. Every geneticist knows that the final expression in the individual of each hereditary determiner is conditioned by the environmental circumstances under which its development is under-

gone. Yet very little has been done in the way of attempting to analyze thoroughly and penetratingly the biological effects of environmental conditions upon human beings.

In truth science, perhaps in common with all other modes of human thought, has a seemingly ineradicable tendency to crystallize its temporarily successful philosophies into dogma, and having accomplished the crystallization proceeds to the scourging of whatever skeptics and heretics may appear. Public-health workers sometimes display a religious attitude toward their achievements as intense as the crusading zeal of the eugenists for their dogmas. Only a few hardy souls throughout history and at the present time seem able to realize for longer than brief periods that new knowledge is more often than in any other way engendered out of skepticism by hard work, and that religious attitudes and modes of thought for however noble a purpose enlisted not only have nothing whatsoever to do with science, but are the most effective hindrances to getting new knowledge yet heard of.

III

Let us now turn to the examination of some of the more conspicuous and far-reaching social consequences of the basic biological principles we have briefly reviewed. The three most obvious and important ones are, I think, that:

1. Man is enjoying better health and individually surviving longer than ever before, likes it, and intends to go farther along the same road.

2. He is vaguely conscious of being more crowded than ever before, and finds the various consequences of this crowding increasingly unpleasant, but chiefly because it threatens that enhanced survival that is always his first and deepest biological concern.

3. Therefore he is groping about to find ways to alleviate the progressive overcrowding and preserve the health and survival gains he has made; trying a great variety of experiments, some of which are sensible, others highly dubious, and a few completely idiotic.

For the sake of clarity these three statements need a little expansion. The urge to survival is the ultimate biological motivating factor that has transferred the maintenance and improvement of health from an individual to a social concern. The gains in this field have been enormous. How enormous perhaps only a statistician can appreciate. This is not the place, nor is there any need, to go into the question of how they have been achieved. But the interesting thing about the case, broadly viewed, is that without the abatement by a single bit of that basic individual selfishness in which the biological urge for survival is rooted, it has been perceived that

this urge can be most effectively served so far as health is concerned by making a social matter of a great part of it. Assuring a pure water supply and innocuously disposing of the waste matters of living are things that the individual simply cannot do well. Society can. And the social progression of the urge to survival in the field of health is by no means at an end yet. In two directions we may confidently look forward to great further changes and advances in the rather immediate future. In the first place, whether we or the physicians like it or not, it seems clear that the maintenance and improvement of individual health is going to become more and more completely a social matter. The basic reasons are two-fold, partly because of the continued normal evolutionary further growth of the same ideas and considerations that have brought us to where we are now regarding public health; partly because of economic and political considerations. The number of persons who at the present time get inadequate medical care because they cannot individually afford to pay for adequate (and lacking it endanger other peoples' health) is so large that as a group they are already in a position politically to demand and get necessary medical service, and may reasonably be counted upon shortly to do so. In the second place it seems reasonable to suppose that advances in medical science are going to continue. The last 75 years—an excessively small fraction of mankind's earthly history—have witnessed more progress in knowledge of disease and its effective treatment and prevention, than was made in all the time that went before. And objectively viewed the rate of advance in medical discovery seems plainly to be accelerating rather than slowing.

Turning now to the consideration of the social consequences of the urge to reproduce, it is immediately to be noted that the growing consciousness of overcrowding—too many people in the world for comfort—is not the resultant of such simple matters as lack of space in which to build dwellings or to move about, or of inability to produce food enough to satisfy the collective hunger. It is true that the total number of living human beings on the globe at this moment is probably something closely approaching 2 billion. But the gross land area of the globe is about 35 billion acres, so that on an equal parceling each individual man, woman, and child would have between 16 and 17 acres. If the total population of the earth were to be forcibly put upon the smallest of the continents—Australia—there would still be, on an equal division, well over an acre for each individual. Similarly relative to food whatever trouble there is relates to distribution rather than production. Such famines as occur now happen not because there is not enough food produced to feed everyone, but because the complex economic mechanism of getting it to the hungry works imperfectly.

The social consequences of population growth present a much more subtle and complicated problem than mere space or food. The suggestion just made that the total land area of the globe might be equally divided per head of population is an obviously fantastic one, with only a sterile arithmetic meaning. Not all the land is equally useful for sustaining human life either directly or indirectly. Some of it is of no use whatever. And this brings us to the crux of the population problem, which is that each unit of the population must somehow or other get its living. All other forms of life except man get their living by one or the other or a combination of two direct ways: These are (1) by preying upon other living things, plant or animal; or (2) directly converting inorganic materials into living substance. Man today gets his living by indirect processes conveniently labeled economic. He is in the main employed in doing things that he can trade with somebody else for the biological requisites for living. The population of the world has now become so large, and the discoveries and applications of science have made the producing of the things that can be traded so much easier than it used to be, that great numbers of people all over the world find themselves unable to get a living by this process that was formerly so relatively simple. The rapid development of the industrial type of civilization in the nineteenth century made the gloomy prophecies of Malthus at its beginning look silly. The population grew at a tremendous pace when he thought its growth would be checked by want and misery. And people were having, by and large, a grand time while their number was increasing; because they were experiencing the enormous improvements in the physical comforts of living that came with the advance and applications of science. But these very factors, plus the enhanced survival rate coincident with the development of public health, cause the ugly spectre of unemployment to rear itself higher and higher until it has now become the most serious problem that humanity faces.

It is to be noted at this point that in modern civilization, as a normal consequence of the relation of individual man's biology to his age, approximately 50 percent of all human beings have to earn the livings not only of themselves but also the major part of that of the other 50 percent. Man develops slowly. Children are incapable of earning their own livings before they are about 15 years old, and have passed approximately a sixth of their total life span, and between a third and a fourth of their average life duration. At the other end of life, for the great majority of human beings over 50 years of age their living must come in whole or in considerable part either from the efforts of the active workers between 15 and 50, or from what they themselves were able to save while they were in their productively efficient ages. In practically all countries the

sum of the numbers of persons under 15 and of those over 50, is almost exactly equal to the number of those between 15 and 50 years of age. But over and above this burden, that may fairly be called a normal biological one, the world's workers are now called upon to support the unemployed. A considerable part of the unemployed are so because they are unemployable—not sufficiently fit and able in a biological sense to make an honest living in a world organized as this one is. These unfit organisms are kept alive by the rest of society for no realistically demonstrable reason other than that they were once born, and by being born somehow placed upon the rest of mankind what has gradually come to be regarded as a permanently binding obligation to see that they do not die. The remainder of the unemployed are so because there are too many fit, able, and employable people in the world to do the necessary world's work, the aggregate amount of which has been, is being, and will continue to be steadily reduced by discoveries and improvements in the sciences and arts.

Mankind is trying in several ways to meet this situation. The first and in the long run perhaps the most important way is by reducing its reproductive rate through the practice of contraception—birth control. It has been seriously alleged and with at least some justification, that even the admittedly imperfect techniques of contraception as they are now known constitute the most important biological discovery ever made. While historians of the subject attempt to show that the practice of contraception is almost if not quite as ancient as man's recorded history, actually the birth rates of large population aggregates did not begin to be sensibly affected by it until roughly the last quarter of the nineteenth century; that is to say, since the beginning of the rapid development of the highly organized, integrated, and urbanized industrial type of civilization. At the present time the effects of contraception on the birth rate are plainly apparent over large and leading parts of the world's population, and are growing at a rather rapid rate.

The practice of birth control is a thoroughly sound, sensible, and in the long run effective method of meeting the problem consequent upon the biological urge to reproduction operating in a universe of definitely limited size. The only objection of importance that can be urged against it is that it has led to an unfavorable differential fertility. The socially and economically more fortunate classes of mankind have practiced contraception more regularly, frequently, and effectively than the less fortunate social and economic classes, with consequently reduced reproductive rates. It is contended that this has brought about a steady deterioration and degeneration of man as a species and will continue to do so until all progress is stopped.

After prolonged study of the matter it is my opinion that the alleged detrimental consequences of this class differential fertility upon the aggregate biological and social fitness and worth of mankind, while doubtless present in some degree, have probably been greatly exaggerated in the reformer's zeal to make his case. This is not the place, nor is there time, to state and document all the reasons that have led me to this view. But there are certain considerations that must be mentioned because they have been so consistently overlooked or suppressed. The first is the tacit assumption that lies at the very root of the argument. This assumption is that, generally speaking and with negligible exceptions, the most fortunate social and economic classes are in that position because they are mainly composed of genetically superior people. But it may be alleged with at least equal truth that these very people who are regarded as mentally, morally, and physically superior are that way (insofar as they are so in fact) in no small part only because they and their forebears have been fortunate socially and economically. The analogy often drawn between human breeding and livestock breeding is in part specious and misleading. In animal breeding it has been learned that the only reliable measure of genetic superiority is the progeny test—the test of quality of the offspring actually produced. Breeding in the light of this test may, and often does, lead to the rapid, sure, and permanent improvement of a strain of livestock. But when the results of human breeding are interpreted in the light of the clear principles of the progeny test the eugenic case does not fare so well. In absolute numbers the vast majority of the most superior people in the world's history have in fact been produced by mediocre or inferior forebears; and furthermore the admittedly most superior folk have in the main been singularly unfortunate in their progeny, again in absolute numbers. No one would question the desirability of the free multiplication of people who are really superior genetically. But in human society as it exists under present conditions of civilization many a gaudy and imposing phenotype masks a very mediocre or worse genotype. And most eugenic selection of human beings is, and in the nature of the case must be, based solely upon phenotypic manifestations.

Naturally it is to be understood that what has been said does not refer to the problem of the really biologically defective and degenerate members of society. There the eugenic position is sound and admirable in principle. The breeding of such people must be stopped; and by compulsory measures. Voluntary birth control will not help appreciably to the solution of the problem, for the persons concerned are not of a sort to make effective use of contraception. If all the contraceptive techniques in the world were made fully

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available to them, they would still go on breeding. There are but three ways, all somewhat imperfect, of dealing with them; they must be segregated, or sterilized, or denied any aid in the struggle for existence and thus allowed and encouraged to perish because too unfit biologically to make livings for themselves with their own unaided resources.

One final point and I shall have done with this phase of our subject. It is a curious fact that at every stage of man's history from at least the time of Plato, and indeed of Theognis of Megara, a century before, there have been those who have been just as certain as some present-day eugenists are, and just as deeply grieved, that mankind was going rapidly to the dogs because the right kind of people were not breeding enough and the wrong kind of people were breeding too much. Perhaps men are nearer the dogs now than they were in the Alexandrian age; but I venture to doubt it. The evidence seems to me overwhelming that mankind is, on an average, mentally, morally, and physically much superior today to what it was when Socrates was abated as a public nuisance.

So much for birth control and the eugenic objections to its alleged consequences. We turn now to the most ineffective, cruel, and altogether foolish large-scale method by which society tries periodically to ameliorate the consequences of the biological urge to reproduction, namely war. If this characterization is reasonably in accord with reality, why do we go on having wars? The reason has been stated with precision by a clear-thinking human biologist, C. C. Walker, in the following words:

> The natural striving after security by one people, that is to say, its natural endeavors to exist must affect the security of other peoples. Because when a people endeavors to ensure its existence, by reason of its automatic reactions to the problems connected with food supply, security, and social stability, its endeavors will conflict with the strivings of other peoples who are also subject to the same environmental problems. Each people is only trying to exist. When a people considers that its existence is threatened by a particular environment, * * * to such an extent that no adaptation to the environment will suffice, it is forced to attempt to alter that environment. But other people may consider that any alteration of that environment affects its own existence. The result is war.

Is there any reason to suppose that this biologically natural process, with its characteristic of almost rhythmic recurrence, will ever come to an end? It seems to me there can be such a hope only in the long —very, very long—run. And the only reason I can see for even this deferred hope is the already great and rapidly increasing ease, speed, and cheapness of transportation and communication between all parts of the world. The slow but steady and sure biological effect of easy getting about will inevitably be more and more interbreeding, with a gradual lessening of the racial and national differences between

human beings. In the far-off end all mankind will presumably be a rather uniform lot; all looking, thinking, and acting pretty much the same way, like sheep. National or racial isolation has even now become extremely difficult to maintain; indeed in a quite literal sense the attempt to maintain such isolations already threatens group survival in not a few instances. In the long run they cannot and will not be maintained. Just in proportion as they diminish so will the frequency of wars diminish. But the diminution seems likely to be at a fearfully slow rate; it will be a long time yet before the last war is fought. And a low cynic might suggest that even war, horrid and stupid as it is, would be preferable to that deadly uniformity among men toward which we are slowly but surely breeding our way.

Society here and abroad is just now experimenting with a whole series of internal readjustments that are being forcibly imposed upon temporarily dazed but always adaptable populations, in the hope that out of them will come a real and permanent solution of the problem that man's urge to reproduction has saddled upon us. All of these experiments appear to fall into a few simple categories when realistically examined. They all stem from and put into practice one or the other of two ideas, neither of which finds unqualified support in the science of biology. The first of these ideas is that it is best to let one individual in a group run the group's affairs; permanently, absolutely and without interference, on the philosophy that averaged opinion and averaged action are as stupid, inefficient, and unreal as an averaged egg is innutritious and unreal. The other and opposite idea is that it is best to have the whole group run the business as a whole, allowing no individual any powers except as a merely mechanical executor of the group's will, on the philosophy that no individual is really superior to another and that therefore in averaged opinion and action wisdom alone resides. In their practical implementation, performance, and effects both ideas turn out to be singularly alike. Both alike scorn the intermediate idea of true democracy. And finally both attempt to solve the problem that is pestering the world by a simple procedure universally regarded as criminal when practiced by an individual. It is that the more abundant life is to be assured to a too abundant people by stealing goods from the prudent and efficient, and then giving them to the imprudent and inefficient. Since there are always a great many more of the latter kind of people than of the former this turns out temporarily to be the most effective political device ever heard of. Whether it will prove to be so permanently is less certain. It has been pointed out earlier in this paper that adaptable as man is there are nevertheless elements of conservative stability in his biological make-up whose roots go back to the very beginning of his evolution. And in that

perfect state of society envisaged by our major prophets, where "economy of plenty" will assure, as we are told, that no one will have to work much for a living, and where the higher philosophy that holds "human rights above property rights" (without perhaps clearly understanding what it means by either) assures that in any event everybody shall be kept alive at public expense whether he works or not, is there not the barest possibility that there might appear a somewhat general inclination on the part of the more intelligent members of the group to opt for the philosophy rather than for the communal work (however slight in amount)? If anything like this should happen might not the economy of plenty some day find itself once again in a parlous state of unplenty? Not being myself a dependable prophet I venture no answer. But in any case, and regardless of details, it is difficult to convince a biologist that a social philosophy will endure for any great length of time that deliberately and complacently loads upon the always weary backs of the able and fit an evergrowing burden. If there is one thing certain in the science of biology it is that no species or variety of plant or animal has long survived that was intrinsically incapable of making its own living. There is somewhere a biological limit to altruism, even for man. A large part of the world today gives the impression that it is determined to find the exact locus of that limit as speedily as possible.

IV

Up to this point the discussion has been of the social consequences of firmly established biological principles. In what regions of biology may there be expected with some confidence developments new in principle, and with important implications for human behavior, thought, and social relations? Probably not, one is fairly safe in saying, in such fields as morphology, embryology, or taxonomy. The advances in the field of genetics, which has to a considerable degree dominated biological thought during nearly a half century and will probably continue to for some time yet, will inevitably have an increasing influence on human affairs as the meaning of its advances is better understood. But this influence seems on the whole likely to be more of a negative than positive character—a matter of avoidances, taboos, and prohibitions rather than of positive contributions to human biological progress. Heredity represents the entailed side of biology—things given—about which it is extremely difficult really to do anything effective in the face of other compelling elements of human life and living, especially those elements belonging in the psycho-biological realm.

It seems probable that advances likely to be made in physiology and psychobiology may profoundly alter human affairs and outlooks

in the not very distant future, and particularly in the direction of the greater release and more effective control of the energies and potentialities of man (and of other living things at will). In recent years the investigations and deductions of the psychiatrists, endocrinologists, and psychobiologists have thrown a beginning glimmer of real light upon the underlying biological bases of the activities and conduct of living things, and especially of man. We are beginning to understand in some detail and particularity how conduct, normal and abnormal, moral and immoral, is the expression of "animal drives" or urges—themselves resultants of subtle chemical and physiological changes in the body—rather than of either free will or terrestrial and heavenly precepts. It does not seem extravagant to expect that as this understanding broadens and deepens ways may be found to bring it about that men will act somewhat more intelligently and less harmfully in politics, business, society, religion, and elsewhere generally, than they sometimes have in the past. The ever widening and deepening flow of biological knowledge is plainly furnishing a solid, scientific groundwork for a philosophy of life based on releases, in contradistinction to the philosophy of life based upon inhibitions and prohibitions that has so long held us enthralled. I am not unaware that current political philosophies in various parts of the world look backward in this regard, and insist on more prohibitions and regimentations. But they are going against biology, and if I read the history of evolution aright, biology will win. Nature is never in a hurry.

This current trend of biology of which we have just been speaking has many different aspects. There are some who will recall the widespread interest and discussion stirred up many years ago by an essay of the late William James entitled "The Energies of Men." It dealt with the release of normally untapped and unsuspected potentialities of men under certain conditions, sometimes those of shock and stress, sometimes under the impulsion of the will. Examples were given of men who, though enfeebled by poor health, performed feats of strength and endurance that would tax the finest athlete, when they encountered conditions that imperatively demanded such a performance.

We are working in the laboratory on another angle of the same general problem. We have experimented with seedlings, grown under very exactly controlled conditions such that all the matter and energy for growth and living (save for water and oxygen) come from the nutritive materials stored in the cotyledons of the seed planted, which themselves are an integral part of the plant. Under these experimental conditions the seedling goes through a complete life cycle of germination, growth, adulthood, senescence, and eventual death. This life cycle corresponds quantitatively very closely to the

normal life cycle of the plant in the field, except that it is greatly compressed and fore-shortened in time. By appropriate aseptic surgical procedures we have removed carefully measured parts of the food resources stored in the cotyledons of the cantaloup seeds we have used, and then observed the relative performance of such mutilated seedlings as compared with the normal controls, in respect of growth and duration of life. The net result is to demonstrate that the mutilated plants grow much larger and live many times longer, as compared with the normal controls, than they would be expected to in proportion to the amount of matter and energy for living available to them after the operation. The results indicated clearly that the operated seedlings utilized their available food resources much more effectively than the normal plant does. It is as though an inhibitor had been removed from the plant, freeing its potentialities for more adequate expression.

The possibilities suggested by these experiments seem far-reaching, though admittedly the exploration of the field has only just begun. Work in this direction on plants and lower animals may result in such an understanding of the physiology of releasing normally inhibited biological potentialities as to enable man to unleash effectively and usefully more of his own energies.

In the field of human biology the admitted and crying need is for adequate synthesis of existing knowledge. It is an obvious truism that we know more in detail about the biology of man than about that of any other organism. Anatomists, physiologists, anthropologists, psychologists, sociologists, and economists have, by analytical methods, piled up a body of detailed information about man that is literally colossal. But what does it mean for humanity? Every thoughtful person will admit that there is a kind of moral necessity to go forward in the attempt to get a better and more comprehensive understanding of the whole nature of man. The material, mechanized civilization he has evolved may easily become a monster to destroy him unless he learns better to comprehend, develop, and control his biological nature. If inventions and discoveries cannot be intelligently managed after they are made, they are likely to be a curse rather than a blessing.

The bulk of scientific effort is, and always has been, directed toward analysis unaccompanied by synthesis. Scientific men have mainly left it to philosophers and literary men to be the synthesizers of their data, shirking the task themselves with a few notable exceptions, of whom perhaps the greatest was a biologist, Charles Darwin. But analysis at best leads only to knowledge; while synthesis may furnish wisdom. And mankind sorely needs more wisdom right here and now!

THE RELATION OF GENETICS TO PHYSIOLOGY AND MEDICINE[1]

By Thomas Hunt Morgan

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[With 2 plates]

The study of heredity, now called genetics, has undergone such an extraordinary development in the present century, both in theory and in practice, that it is not possible in a short address to review even briefly all its outstanding achievements. At most I can do no more than take up a few topics for discussion.

Since the group of men with whom I have worked for 20 years has been interested for the most part in the chromosome mechanism of heredity, I shall first briefly describe the relation between the facts of heredity and the theory of the gene. Then I should like to discuss one of the physiological problems implied in the theory of the gene, and, finally, I hope to say a few words about the applications of genetics to medicine.

The modern theory of genetics dates from the opening years of the present century with the discovery of Mendel's long-lost paper that had been overlooked for 35 years. The data obtained by de Vries in Holland, Correns in Germany, and Tschermak in Austria showed that Mendel's laws are not confined to garden peas, but apply to other plants. A year or two later the work of Bateson and Punnett in England and Cuénot in France made it evident that the same laws apply to animals.

In 1902 a young student, William Sutton, working in the laboratory of E. B. Wilson, pointed out clearly and completely that the known behavior of the chromosomes at the time of maturation of the germ-cell furnishes us with a mechanism that accounts for the kind of separation of the hereditary units postulated in Mendel's theory.

The discovery of a mechanism that suffices to explain both the first and the second law of Mendel has had far-reaching consquences for

[1] Nobel lecture, presented in Stockholm on June 4, 1934. Reprinted by permission from the Scientific Monthly, July 1935.

genetic theory, especially in relation to the discovery of additional laws, because the recognition of a mechanism that can be seen and followed demands that any extension of Mendel's theories must conform to such a recognized mechanism, and also because the apparent exceptions to Mendel's laws that came to light before long might in the absence of a known mechanism have called forth purely fictitious modifications of Mendel's laws or even seemed to invalidate their generality. We now know that some of these "exceptions" are due to newly discovered and demonstrable properties of the chromosome mechanism and others to recognizable irregularities in the machine.

Mendel knew of no processes taking place in the formation of pollen and egg cell that could furnish a basis for his primary assumption that the hereditary elements separate in the germ cells in such a way that each ripe germ cell comes to contain only one of each kind of element; but he justified the validity of this assumption by putting it to a crucial test. His analysis was a wonderful feat of reasoning. He verified his reasoning by the recognized experimental procedure of science.

As a matter of fact, it would not have been possible in Mendel's time to give an objective demonstration of the basic mechanism involved in the separation of the hereditary elements in the germ cells. The preparation for this demonstration took all the 35 years between Mendel's paper in 1865 and 1900. It is here that the names of the most prominent European cytologists stand out as the discoverers of the role of the chromosomes in the maturation of the germ cells. It is largely a result of their work that it was possible in 1902 to relate the well-known cytological evidence to Mendel's laws. So much in retrospect.

The most significant additions that have been made to Mendel's two laws may be called "linkage" and "crossing over." In 1906 Bateson and Punnett reported a two-factor case in sweet peas that did not give the expected ratio for two pairs of characters entering the cross at the same time.

By 1911 two genes had been found in *Drosophila* that gave sex-linked inheritance. It had earlier been shown that such genes lie in the X-chromosomes. Ratios were found in the second generation that did not conform to Mendel's second law when these two pairs of characters are present, and the suggestion was made that the ratios in such cases could be explained on the basis of interchange between the two X-chromosomes in the female. It was also pointed out that the further apart the genes for such characters happen to lie in the chromosome the greater the chance for interchange to take place. This would give the approximate location of the genes with respect to other genes. By further extension and

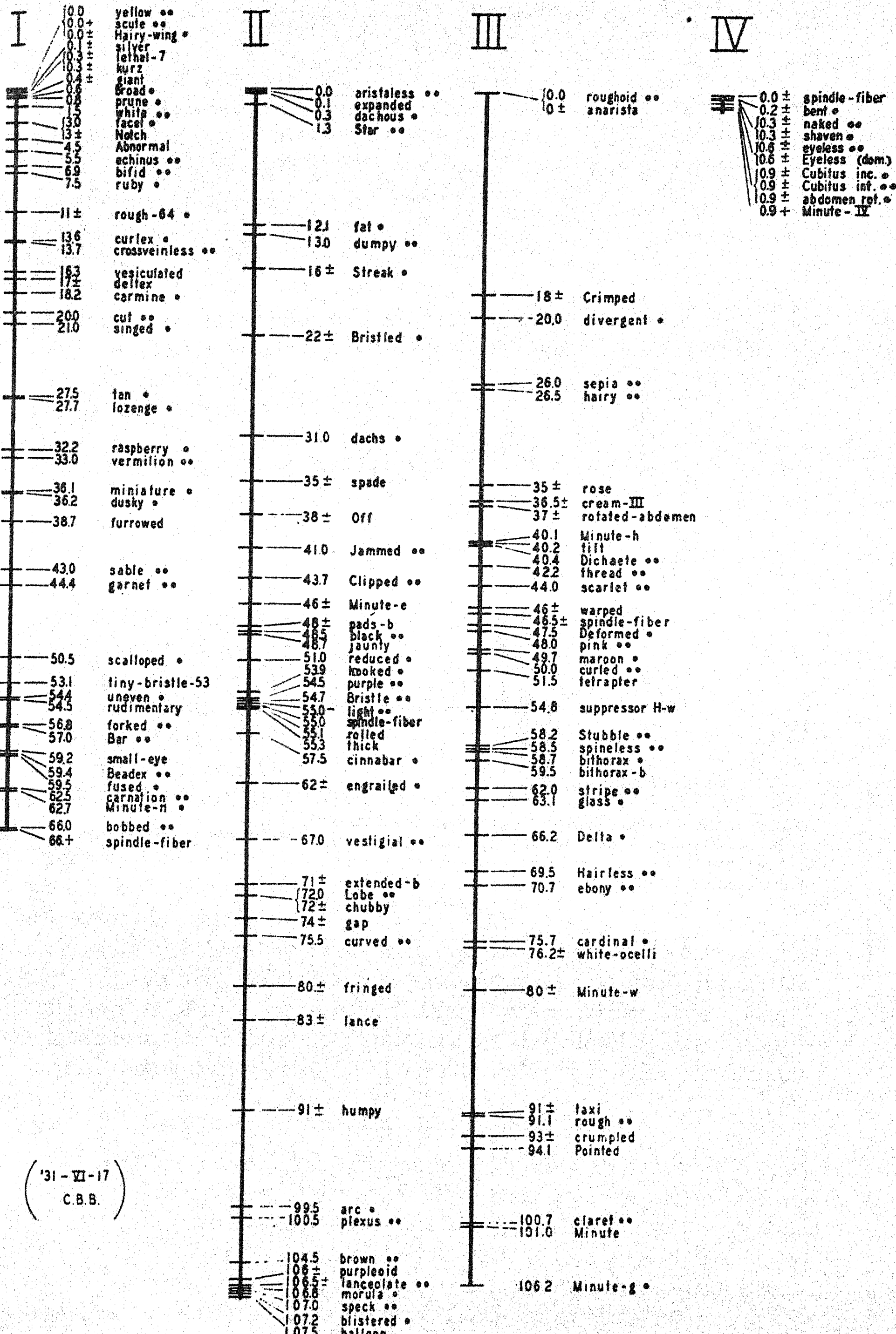


FIGURE 1.—Genetic map of the four chromosomes of *Drosophila melanogaster*, showing the linear order and relative distance apart of the genes. (After Bridges.)

clarification of this idea it became possible, as more evidence accumulated, to demonstrate that the genes lie in a single line in each chromosome.

Two years previously (1909) a Belgian investigator, Janssens, had described a phenomenon in the conjugating chromosomes of a salamander, *Batracoseps*, which he interpreted to mean that interchanges take place between homologous chromosomes. This he called "chiasmatypie"—a phenomenon that has occupied the attention of cytologists down to the present day. Janssens' observations were destined shortly to supply an objective support to the demonstration of genetic interchange between linked genes carried in the sex chromosomes of the female *Drosophila*.

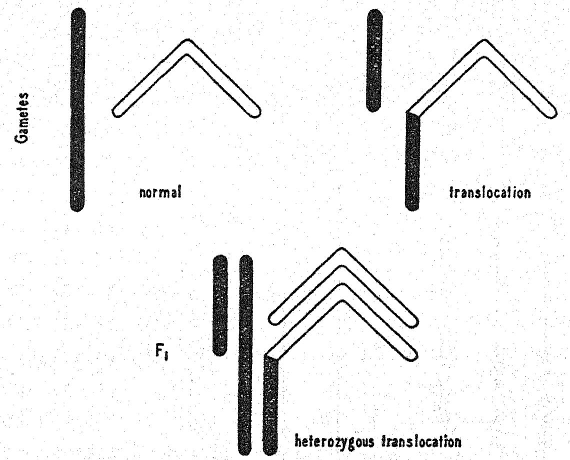


FIGURE 2.—Diagram to illustrate the case when a piece of one chromosome (black) has been translocated to another chromosome (white). In the lower part of the figure the method of conjugation of these chromosomes is shown.

Today we arrange the genes in a chart or map, figure 1. The numbers attached express the distance of each gene from some arbitrary point taken as zero. These numbers make it possible to foretell how any new character that may appear will be inherited with respect to all other characters as soon as its crossing-over value with respect to any other two characters is determined. This ability to predict would in itself justify the construction of such maps, even if there were no other facts concerning the location of the genes; but there is today direct evidence in support of the view that genes lie in a serial order in the chromosomes.

WHAT ARE THE GENES?

What is the nature of the elements of heredity that Mendel postulated as purely theoretical units? What are genes? Now that we locate them in the chromosomes are we justified in regarding them as material units; as chemical bodies of a higher order than molecules? Frankly, these are questions with which the working geneticist has not much concern himself, except now and then to speculate as to the nature of the postulated elements. There is no consensus of opinion amongst geneticists as to what the genes are—whether they are real or purely fictitious—because at the level at

which the genetic experiments lie it does not make the slightest difference whether the gene is a hypothetical unit or whether the gene is a material particle. In either case the unit is associated with a specific chromosome and can be localized there by purely genetic analysis. Hence, if the gene is a material unit, it is a piece of a chromosome; if it is a fictitious unit, it must be referred to a definite location in a chromosome—the same place as on the other hypothesis. Therefore, it makes no difference in the actual work in genetics which point of view is taken.

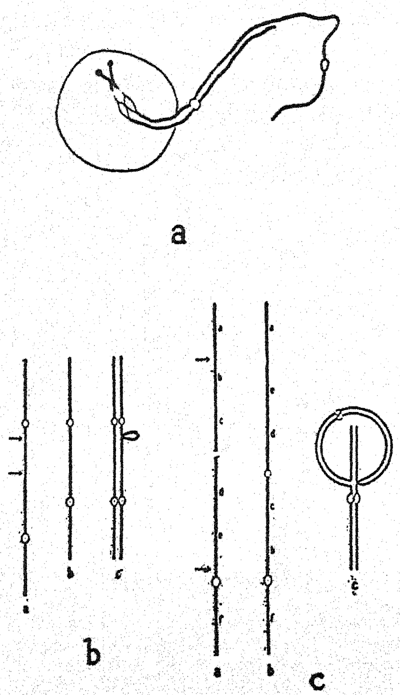


FIGURE 3.—(*a*) Two conjugating chromosomes of Indian corn (after McClintock). One chromosome has a terminal deficiency. (*b*) Two chromosomes of Indian corn, one having a deficiency near its middle. When these two chromosomes conjugate there is a loop in the longer chromosome opposite the deficiency in the other one. (*c*) Two chromosomes of Indian corn, one having a long inverted region. When they conjugate they come together as shown in the figure to the right, like genes coming together.

Between the characters that are used by the geneticist and the genes that the theory postulates lies the whole field of embryonic development, where the properties implicit in the genes become explicit in the protoplasm of the cells. Here we appear to approach a physiological problem, but one that is new and strange to the classical physiology of the schools.

We ascribe certain general properties to the genes, in part from genetic evidence and in part from microscopical observations. These properties we may next consider.

Since chromosomes divide in such a way that the line of genes is split (each daughter chromosome receiving exactly half of the original line) we can scarcely avoid the inference that the genes divide into exactly equal parts; but just how this takes place is not known. The analogy of cell division creates a presumption that the gene divides in the same way, but we should not forget that the relatively gross process involved in cell division may seem quite inadequate to cover the refined separation of the gene into equal halves. As we do not know of any comparable division phenomena in organic molecules, we must also be careful in ascribing a simple molecular constitution to the gene. On the other hand, the elaborate chains of molecules built up in organic material may give us, some day, a better opportunity to

picture the molecular or aggregate structure of the gene and furnish a clue concerning its mode of division.

Since by infinite subdivisions the genes do not diminish in size or alter as to their properties, they must, in some sense, compensate by growing between successive divisions. We might call this property autocatalysis, but, since we do not know how the gene grows, it is somewhat hazardous to assume that its property of growth after division is the same process that the chemist calls autocatalytic. The comparison is at present too vague to be reliable.

The relative stability of the gene is an inference from genetic evidence. For thousands—perhaps many millions—of subdivisions of its material it remains constant. Nevertheless, on rare occasions, it may change. We call this change a mutation, following de Vries' terminology. The point to emphasize here is that the mutated gene retains, in the great majority of cases studied, the property of growth and division, and more important still the property of stability. It is, however, not necessary to assume, either for the original genes or for the mutated genes, that they are all equally stable. In fact, there is a good deal of evidence for the view that some genes mutate oftener than others, and in a few cases the phenomenon is not infrequent, both in the germ-cells and in somatic tissues. Here the significant fact is that these repetitional changes are in definite and specific directions.

The constancy of position of genes with respect to other genes in linear order in the chromosomes is deducible, both from genetic evidence and from cytological observations. Whether the relative position is no more than a historical accident or whether it is due to some relation between each gene and its neighbors cannot be definitely stated. But the evidence from the dislocation of a fragment of the chromosome and its reattachment to another one indicates that accident rather than mutual interaction has determined their present location; for, when a piece of one chromosome becomes attached to the end of a chain of genes of another chromosome or when a section of a chromosome becomes inverted, the genes in the new position hold as fast together as they do in the normal chromosome.

There is one point of great interest. So far as we can judge from the action of mutated genes, the kind of effect produced has as a rule no relation to location of the gene in the chromosome. A gene may produce its chief effect on the eye color, while one nearby may affect the wing structure, and a third, in the same region, the fertility of the male or of the female. Moreover, genes in different chromosomes may produce almost identical effects on the same organs. One may say, then, that the position of the genes in the hereditary material is inconsequential in relation to the effects that they produce. This leads

to a consideration which is more directly significant for the physiology of development.

In the earlier days of genetics it was customary to speak of unit characters in heredity, because certain contrasted characters, rather clearly defined, furnished the data for the Mendelian ratios. Certain students of genetics inferred that the Mendelian units responsible for the selected character were genes producing only a single effect. This was careless logic. It took a good deal of hammering to get rid of this erroneous idea. As facts accumulated it became evident that each gene produces not a single effect, but in some cases a multitude of effects on the characters of the individual. It is true that in most genetic work only one of these character effects is selected for study—the one that is most sharply defined and separable from its contrasted character—but in most cases minor dif-

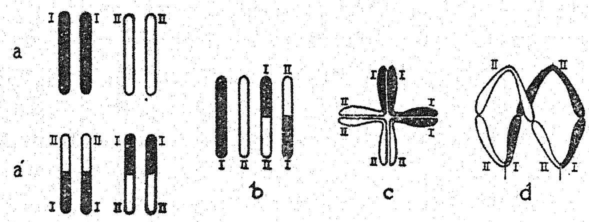


FIGURE 4.—Diagram of *Oenothera* chromosomes illustrating the configuration of chromosomes (c and d) when there has been an exchange between different chromosomes as indicated in the figure by the black and white. In a and a' an exchange between chromosomes I and II is shown. In b the chromosome group is drawn, in which there are two interchanged chromosomes and two whole chromosomes. In c the coming together of these four chromosomes is shown, and in d the results of the opening out of this cross into a twisted ring. Chromosome pairs, that came in together, pass to opposite poles.

ferences also are recognizable that are just as much the product of the same gene as is the major effect. In fact, the major difference selected for classification of the contrasted character-pairs may be of small importance for the welfare of the individual, while some of the concomitant effects may be of vital importance for the economy of the individual, affecting its vitality, its length of life, or its fertility. I need not dwell at length on these relations because they are recognized today by all geneticists. It is important, nevertheless, to take cognizance of them, because the whole problem of the physiology of development is involved.

The coming together of the chromosomes at the maturation division, and their subsequent movement apart to opposite poles of the meiotic figure, insures the regular distribution of one set of chromosomes to each daughter-cell and the fulfilment of Mendel's second law. These movements have the appearance of physical events. Cytologists speak of these two phenomena as attraction and

repulsion of the members of individual chromosomes, but we have no knowledge of the kind of physical processes involved. The terms attraction and repulsion are purely descriptive, and mean no more at present than that like chromosomes come together and later separate.

In earlier times, when the constitution of the chromosomes was not known, it was supposed that the chromosomes come together at random in pairs. There was the implication that any two chromosomes may mate. The comparison with conjugation of male and female protozoon, or egg and sperm-cell, was obvious, and since in all diploid cells one member of each pair of chromosomes has come from the father and one from the mother, it must have seemed that somehow maleness and femaleness are involved in the conjugation of the

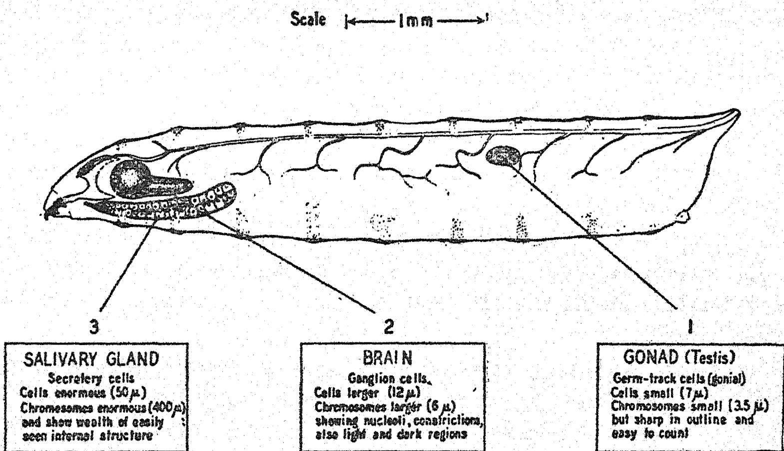


FIGURE 5.—Diagram of larva of *Drosophila melanogaster*, showing the gonad, brain, and one of the salivary glands.

chromosomes also. But today we have abundant evidence to prove that this idea is entirely erroneous, since there are cases where both chromosomes that conjugate have come from the female, and even where both have been sister strands of the same chromosome.

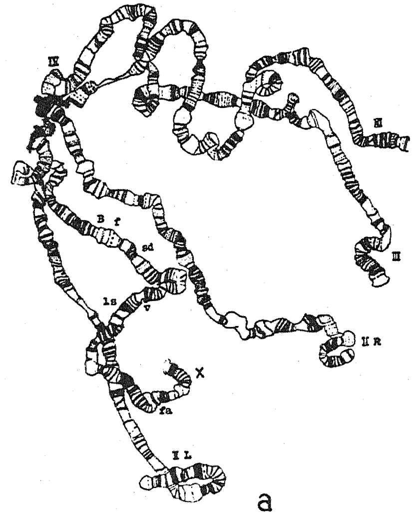
Recent genetic analysis shows not only that the conjugating chromosomes are like chromosomes, i. e., chains of the same genes, but also that very exact processes are involved. The genes come together, point for point, unless some physical obstacle prevents. The last few years have furnished some beautiful illustrations showing that it is genes rather than whole chromosomes that come to lie side by side when the chromosomes come together. For example, occasionally a chromosome may have a piece broken off (fig. 2, above) which becomes attached to another chromosome. A new linkage group is thus established. When conjugation takes place this piece

has no corresponding piece in the sister chromosome. It has been shown (fig. 2) that it then conjugates with that part of the parental chromosomes from which it came.

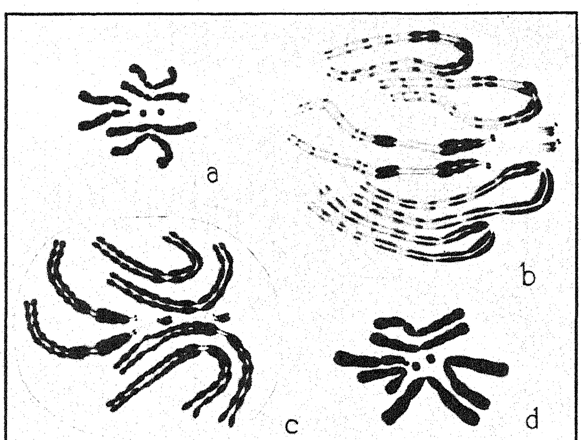
When a chromosome has lost one end, it conjugates with its mate only in part (fig. 3a), i. e., where like genes are present. When a chromosome has lost a small region, somewhere along its length, so that it is shorter than the original chromosome, the larger chromosome shows a loop which is opposite the region of deficiency in the shorter chromosome as shown in figure 3b. Thus like genes, or corresponding loci, are enabled to come together through the rest of the chromosome. More remarkable still is the case where the middle region of a chromosome has become turned around (inversion). When such a chromosome is brought together with its normal homologue, as shown in figure 3c, like regions come together by the inverted piece reversing itself, so to speak, so that like genes come together as shown to the right in figure 3c. In this same connection the conjugation of the chromosomes in species of *Oenothera* (fig. 4) furnish beautiful examples of the way in which like series of genes find each other, even when halves of different chromosomes have been interchanged.

The very recent work of Heitz, Painter, and Bridges has brought to light some astonishing evidence relating to the constitution of the chromosomes in the salivary glands of *Drosophila*, figures 5–8; plates 1 and 2.

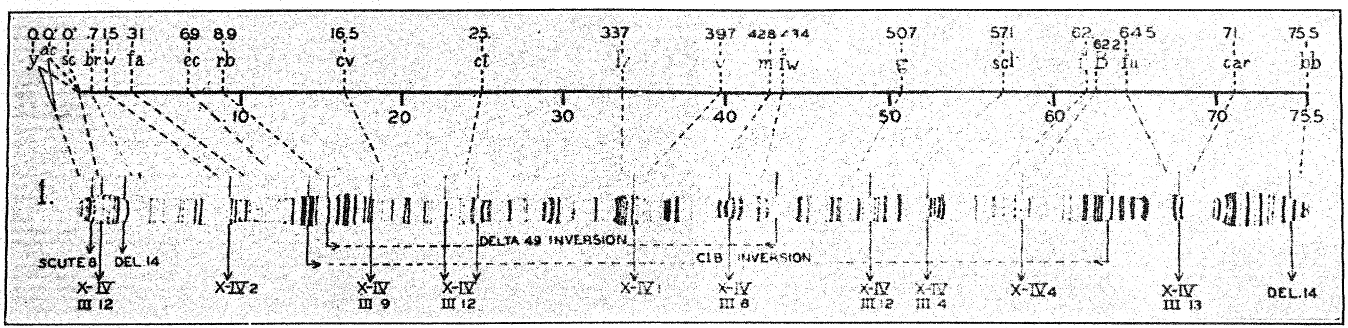
The nuclei of the cells of the salivary glands of the old larvae are very large and their contained chromosomes may be 70 to 150 times as long as those of the ordinary chromosomes in process of division. Heitz has shown that there are regions of some of the chromosomes of the ganglion cells—more especially of the X and the Y chromosomes—that stain deeply, and other regions faintly (pl. 1, fig. 2), and that these regions correspond to regions of the genetic map that do not and do contain genes. Painter has made the further important contribution that the series of bands of the salivary chromosomes can be homologized with the genetically known series of genes of the linkage maps (pl. 1, fig. 1, and pl. 2) and that the empty regions of the X and Y do not have the banded structure. He has further shown that when a part of the linkage map is reversed the sequence of the bands is also reversed; that when pieces are translocated they can be identified by characteristic bands; and that when pieces of linked genes are lost there is a corresponding loss of bands. Bridges has carried the analysis further by an intensive study of regions of particular chromosomes and has shown a close agreement between bands and gene location. With improved methods he has identified twice as many bands, thus making a more complete



1. The chromosomes of the salivary gland of the female larva of *Drosophila melanogaster* (after Painter). The two X-chromosomes are fused into a single body. This chromosome is attached at one end to the common chromocenter at its attachment end. The second and third chromosomes have the attachment point near the middle and are fused with the common chromocenter at this point, leaving two free ends of each chromosome. Like limbs of each of these free ends are fused, giving four free ends in all.



2. The relative sizes of the chromosomes in the cells of the gonad (*a*), of the giant ganglion cells of the brain (*d*), and of the prophase stage of the latter (*b*, *c*). In (*a*) a metaphase plate from the gonad is shown. In (*b*) a prophase stage from a ganglion cell showing the black (heavily stained) inert regions of the chromosomes and the faintly stained regions carrying most of the genes, according to Heitz. In (*c*) the late prophase of the same type of cell is shown intermediate between (*b*) and (*d*). The genetic region is now stained. In (*d*) (male) the metaphase of a ganglion cell has chromosomes larger than those of the gonad cells as shown in (*a*).



The banded salivary X-chromosome of *Drosophila melanogaster* is below, with the genetic map above. Oblique broken lines connect regions of the genetic map with corresponding or homologous regions of the salivary chromosome.

analysis of the relation of bands and gene location. Thus, whether or not the bands are the actual genes, the evidence is clear in showing a remarkable agreement between the location of genes and the location of corresponding bands. The analysis of the banded structure has confirmed the genetic evidence, showing that when certain alterations of the order of the genes takes place there is a corresponding change in the sequence of the bands which holds for the finest details of the bands.

The number of chromosomes in the salivary nuclei is half that of the full number (as reported by Heitz), which Painter interprets as due to homologous chromosomes conjugating (pl. 1, fig. 1). Moreover, the bands in each of the component halves show an identical sequence which is strikingly evident when the halves are not closely apposed. It has been suggested by Bridges and by Koltzoff that

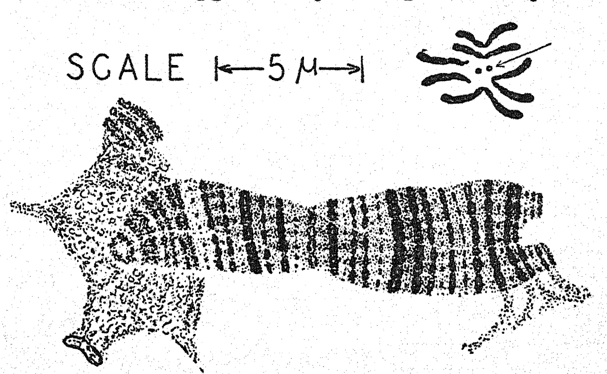


FIGURE 6.—Above to right the four pairs of chromosomes of *Drosophila* in the metaphase stage from a cell of the ovary. The two smallest chromosomes are in the middle of the group. The same chromosomes from the salivary gland are drawn below to the same scale (after Bridges from the Journal of Heredity).

homologous chromosomes have not only united but that they have each divided two or three times, giving in some cases as many as 16 or 32 strands (fig. 6). The bands may then be said to be composed each of 16 or 32 genes; or, if this identification of the bands as genes is questioned insofar as the genes are concerned, the bands are multiples of some kind of unit of which the chromosomes are composed.

A few examples may serve to illustrate the way in which the banded chromosomes confirm the genetic conclusions as to occasional changes that have taken place in the serial order of the genes. In figure 7 the right half of chromosome 3 from the salivary gland is represented. In part the two components are fused, in part are separate. In the lower part of the figure a reversed piece of one component is present (terminal inversion). Like bands conjugate

with like and, as shown in the smaller diagram above, figure 7, this is made possible by the end of one component turning back on itself. In figure 8 is drawn a short region of chromosome 2. One component has a deficiency for certain genes; the opposite normal chromosome forms a bulge in the region of the deficiency, allowing like bands to come together above and below the deficiency level.

THE PHYSIOLOGICAL PROPERTIES OF THE GENES

If, as is generally implied in genetic work (although not often explicitly stated), all the genes are active all the time, and if the

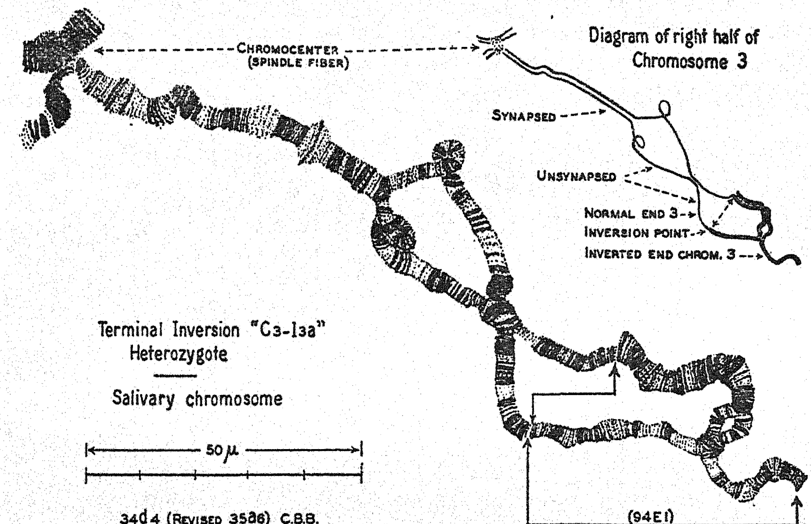


FIGURE 7.—Salivary gland preparation of right arm of the third chromosome, illustrating a terminal inversion in one of the two components. The two components are fused together throughout part of their length and are separate in other parts as shown in the small diagram above and to right. The terminal inversion conjugates with the noninverted end by turning back, as proved by the sequence of the bands. (After Bridges.)

characters of the individual are determined by the genes, then why are not all the cells of the body exactly alike?

The same paradox appears when we turn to the development of the egg into an embryo. The egg appears to be an unspecialized cell, destined to undergo a prescribed and known series of changes leading to the differentiation of organs and tissues. At every division of the egg the chromosomes split lengthwise into exactly equivalent halves. Every cell comes to contain the same kinds of genes. Why, then, is it that some cells become muscle cells, some nerve cells, and others remain reproductive cells?

The answer to these questions seemed relatively simple at the end of the last century. The protoplasm of the egg is visibly different

at different levels. The fate of the cells in each region is determined, it was said, by the differences in different protoplasmic regions of the egg.

Such a view is consistent with the idea that the genes are all acting; the initial stages of development being the outcome of a reaction between the identical output of the genes and the different regions of the egg. This seemed to give a satisfactory picture of development, even if it did not give us a scientific explanation of the kind of reactions taking place.

But there is an alternative view that cannot be ignored. It is conceivable that different batteries of genes come into action one after the other, as the embryo passes through its stages of development. This sequence might be assumed to be an automatic property of the chain of genes. Such an assumption would, without proof, beg the

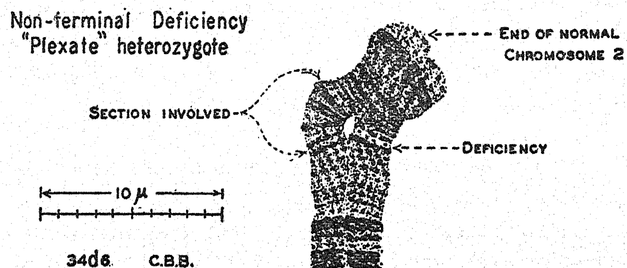


FIGURE 8.—Salivary gland preparation showing a part of chromosome 2. There is a deficiency in one of the two conjugants. At the level of the deficiency the other component is bent outward, so that above and below this level like bands meet. This figure also shows that the salivary chromosomes are made up of 16 strands, the 16 elements of which fuse together to make each of the cross bands. (After Bridges.)

whole question of embryonic development, and could not be regarded as a satisfactory solution. But it might be that in different regions of the egg there is a reaction between the kind of protoplasm present in those regions and specific genes in the nuclei; certain genes being more affected in one region of the egg, other genes in other regions. Such a view might give also a purely formal hypothesis to account for the differentiation of the cells of the embryo. The initial steps would be given in the regional constitution of the egg.

The first responsive output of the genes would then be supposed to affect the protoplasm of the cells in which they lie. The changed protoplasm would now act reciprocally on the genes, bringing into activity additional or other batteries of genes. If true this would give a pleasing picture of the developmental process. A variation of this view would be to assume that the product of one set of genes is gradually in time overtaken and nullified or changed by the slower development of the output of other genes, as Goldschmidt, for ex-

ample, has postulated for the sex-genes. In the last case the theory is dealing with the development of hybrid embryos whose sex-genes are assumed to have different rates of activity.

A third view may also be permissible. Instead of all the genes acting in the same way all the time or instead of certain kinds of genes coming successively into action, we might postulate that the kind of activity of all the genes is changed in response to the kind of protoplasm in which they lie. This interpretation may seem less forced than the others, and in better accord with the functional activity of the adult organ-systems.

We must wait until experiments can be devised that will help us to discriminate between these several possibilities. In fact, geneticists all over the world are today trying to find methods that will help to determine the relation of genes to embryonic and adult characters. The problem (or problems) is being approached both from a study of chemical changes that take place near the final steps in organ formation, especially in the development of pigments, and from a study of the early differentiation of the cell groups of the embryo.

We have also come to realize that the problem of development is not as simple as I have so far assumed to be the case, for it depends, not only on independent cell differentiation of individual cells, but also on interactions between cells, both in the early stages of development and on the action of hormones on the adult organ systems. At the end of the last century, when experimental embryology greatly flourished, some of the most thoughtful students of embryology laid emphasis on the importance of the interaction of the parts on each other, in contrast to the theories of Roux and Weismann that attempted to explain development as a progressive series of events that are the outcome of self-differentiating processes or, as we would say today, by the sorting out of genes during the cleavage of the egg. At that time there was almost no experimental evidence as to the nature of the postulated interaction of the cells. The idea was a generalization rather than an experimentally determined conclusion, and, unfortunately, took a metaphysical turn.

Today this has changed, and owing mainly to the extensive experiments of the Spemann School of Germany, and to the brilliant results of Hörstadius, of Stockholm, we have positive evidence of the far-reaching importance of interactions between the cells of different regions of the developing egg. This implies that original differences are already present, either in the undivided egg or in the early formed cells of different regions. From the point of view under consideration results of this kind are of interest because they bring up once more, in a slightly different form, the problem as to

whether the organizer acts first on the protoplasm of the neighboring region with which it comes in contact, and through the protoplasm of the cells on the genes; or whether the influence is more directly on the genes. In either case the problem under discussion remains exactly where it was before. The conception of an organizer has not as yet helped to solve the more fundamental relation between genes and differentiation, although it certainly marks an important step forward in our understanding of embryonic development.

GENETICS AND MEDICINE

That man inherits his characters in the same way as do other animals there can be no doubt. The medical literature contains hundreds of family pedigrees, in which certain characters, usually malformations, appear more frequently than in the general population. Most of these are structural defects; a few are physiological traits (such as haemophilia); others are psychopathic. Enough is already known to show that they follow genetic principles.

Man is a poor breeder—hence many of these family pedigrees are too meager to furnish good material for genetic analysis. When an attempt is made to combine pedigrees from different sources in order to insure sufficient data, the question of correct diagnosis sometimes presents serious difficulties, especially in the older materials; but with the very great advances that have been made in medical diagnosis in recent years this difficulty will certainly be less serious in the future.

The most important contribution to medicine that genetics has made is, in my opinion, intellectual. I do not mean to imply that the practical applications are unimportant, and I shall in a moment point out some of the more obvious connections, but the whole subject of human heredity in the past (and even at the present time in uninformed quarters) has been so vague and tainted by myths and superstitions that a scientific understanding of the subject is an achievement of the first order. Owing to genetic knowledge medicine is today emancipated from the superstition of the inheritance of maternal impressions: it is free from the myth of the transmission of acquired characters, and in time the medical man will absorb the genetic meaning of the role of external environment in the coming to expression of genetic characters.

The importance of this relation will be seen when it is recalled that the germ-plasm, or, we say, the genic composition of man is a very complex mixture—much more so than that of most other animals, because in very recent times there has been a great amalgamation of many different races owing to the extensive migration of the human animal, and also because man's social institutions help to

keep alive defective types of many kinds that would be eliminated in wild species through competition. Medicine has been, in fact, largely instrumental in devising means for the preservation of weak types of individuals, and in the near future medical men will, I suggest, often be asked for advice as to how to get rid of this increasing load of defectives. Possibly the doctor may then want to call in his genetic friends for consultation. The point I want to make clear is that the complexity of the genic composition of man makes it somewhat hazardous to apply only the simpler rules of Mendelian inheritance; for the development of many inherited characters depends both on the presence of modifying factors and on the external environment for their expression.

I have already pointed out that the gene generally produces more than one visible effect on the individual, and that there may be also many invisible effects of the same gene. In cases where a condition of susceptibility to certain diseases is present, it may be that a careful scrutiny will detect some minor visible effects produced by the same gene. As yet our knowledge on this score is inadequate, but it is a promising field for further medical investigation. Even the phenomenon of linkage may some day be helpful in diagnosis. It is true there are known as yet in man no certain cases of linkage, but there can be little doubt that there will in time be discovered hundreds of linkages, and some of these, we may anticipate, will tie together visible and invisible hereditary characteristics. I am aware, of course, of the ancient attempts to identify certain gross physical human types—the bilious, the lymphatic, the nervous, and the sanguine dispositions and of more modern attempts to classify human beings into the cerebral, respiratory, digestive, and muscular, or more briefly, into asthenics and pycnics. Some of these types are supposed to be more susceptible to certain ailments or diseases than are other types, which in turn have their own constitutional characteristics. These well-intended efforts are, however, so far in advance of our genetic information that the geneticist may be excused if he refuses to discuss them seriously.

In medical practice the physician is often called upon for advice as to the suitability of certain marriages where a hereditary taint is present in the ancestry. He is often called upon to decide as to the risk of transmitting certain abnormalities that have appeared in the first-born child. Here genetics will, I think, be increasingly helpful in making known the risk incurred and in distinguishing between environmental and hereditary traits.

Again, a knowledge of the laws of transmission of hereditary characters may sometimes give information that may be helpful in the diagnosis of certain diseases in their incipient stages. If, for

example, certain stigmata appear whose diagnosis is uncertain, an examination of the family pedigree of the individual may help materially in judging as to the probability of the diagnosis.

I need scarcely point out those legal questions concerning the paternity of an illegitimate child. In such cases a knowledge of the inheritance of blood groups, about which we now have very exact genetic information, may often furnish the needed information.

Geneticists can now produce, by suitable breeding, strains of populations of animals and plants that are free from certain hereditary defects; and they can also produce, by breeding, plant populations that are resistant or immune to certain diseases. In man it is not desirable, in practice, to attempt to do this, except insofar as here and there a hereditary defective may be discouraged from breeding. The same end is accomplished by the discovery and removal of the external causes of the disease (as in the case of yellow fever and malaria) rather than by attempting to breed an immune race. Also, in another way the same purpose is attained in producing immunity by inoculation and by various serum treatments. The claims of a few enthusiasts that the human race can be entirely purified or renovated, at this later date, by proper breeding, have, I think, been greatly exaggerated. Rather must we look to medical research to discover remedial measures to insure better health and more happiness for mankind.

While it is true, as I have said, some little amelioration can be brought about by discouraging or preventing from propagating well-recognized hereditary defects (as has been done for a long time by confinement of the insane), nevertheless it is, I think, through public hygiene and protective measures of various kinds that we can more successfully cope with some of the evils that human flesh is heir to. Medical science will here take the lead—but I hope that genetics can at times offer a helping hand.

CONSERVATION OF THE PACIFIC HALIBUT, AN INTERNATIONAL EXPERIMENT

By William F. Thompson
International Fisheries Commission, United States and Canada, Seattle, Wash.

[With 2 plates]

When Canada and the United States ratified the Pacific halibut treaty on October 21, 1924, there was begun the first international attempt at conservation and rebuilding of a marine fishery. It applied to the Pacific coast halibut, the giant flounder that lives on the continental shelf from California to Bering Sea.

This first treaty placed in the hands of an international commission power to gather facts uniformly, as a joint enterprise, in both the United States and Canada. Six years later the treaty was rewritten to give it powers of regulation in conformity with its findings. Today it can report initial success in a difficult problem, for since the new treaty came into being in 1931 the halibut banks have steadily improved.

The members of the International Fisheries Commission at its inception in 1924 were as follows: John P. Babcock, Victoria, B. C., chairman; Miller Freeman, Seattle, Wash., secretary; Henry O'Malley, Washington, D. C.; and William A. Found, Ottawa, Canada. Mr. O'Malley and Mr. Freeman have resigned. In their places, Frank T. Bell, Washington, D. C., and Edward W. Allen, Seattle, Wash., have been appointed, the latter now being secretary.

Marine fisheries, of which that for halibut is the most truly deep-sea, have given both scientist and economist a subject for earnest consideration during the past 40 years. They are immensely valuable, and yet not enough is known of most of them either to confirm or deny serious uneasiness as to their permanence. This lack of knowledge is due not only to their inaccessibility, but to their newness; not only to the difficulty of obtaining proper international cooperation in their study, but also to the complexity of the biological problem involved.

They differ from all other resources other than water and air in being mainly in international waters. National ownership of land

and its resources came into being because exclusive rights are valuable to the people owning them, and national governments exist to guard this ownership. But national governments and national domain assumed definite legal form and limitations long before exclusive ownership of a fishery appeared worthy of much attention. International maritime usages had developed too far before the need for protection and conservation became plain. In fact, it was not until our scientific age provided power to move vessels and trains, to make ice and haul fishing gear, to build cities and import food, that the great marine fisheries other than those for salted herring and cod began to grow beyond the status of small-boat alongshore industries. In a very real sense our greatest fisheries are really not older than men now in full vigor, born in the eighties. So abrupt has been this growth, so new its consequences, that overnight nations have found themselves competing with other nations on the same grounds for a vital raw supply, with their own fleets and governments already committed more to freedom of access to banks on other coasts than to conservation of those on their own.[1] Exploited more slowly, property rights to banks nearest to their lands might have gradually grown up. But now, for better or for worse, these great resources are mainly international. They are everybody's property, nobody's particular responsibility; and, just as in armaments, no one wishes to take the first step of self-restraint.

Indeed, there is difficulty in even deciding what should be done with them, for a biological problem of first magnitude is involved. Fishing, from the standpoint of the fish, is just a greatly increased mortality rate at certain sizes. Its effects are bound up with the mechanism that enables a species to survive mortality changes. There is but little difference between man as he affects the fish he catches and a kind of disease, or a change in the environment that kills an unusually great number of individuals of special sizes. That a fish may survive through the ages, some mechanism to handle the recurring periods of greater or less mortality must exist; so that, strangely enough, essentially the same biological complex must explain both the reaction of a species to fishing and its evolution and survival. And to understand it the species as a whole or at least an independent part must be studied with complete ability to measure the mortality, the growth, and the movements to and fro.

The task entrusted to the International Fisheries Commission has therefore been in a very direct way a challenge to the biologist. He is asked to explain this biological complex that governs a valuable resource and to show how it may be used without destroying it. To be sure, the treaty gives him great advantages. The problem

[1] Fulton, Sovereignty of the Seas, pp. 108, 737.

can be brought together and grasped as a whole through a unified, complete system of statistical observation that does not recognize boundary lines—a vital matter, for it could not be understood if but a part could be seen. For that reason the challenge is a very real one and the responsibility great.

A partial answer cannot suffice. Scientists have worked out rates of growth of fish, then have given their guess as to what restraint is necessary; they have discovered spawning seasons and times, then have said that such times were or were not proper for fishing. Little concrete reasoning had connected interesting fact and proposed regulation. This cannot in good faith be the answer to this problem.

When the Commission was created, it faced a great depletion of the supply, especially on the nearby banks. Its first step, that of any good scientist, was to gather and analyze all the available information regarding the fishery and its history. It found the halibut fishery splendidly adapted for this purpose because it was carried on by a homogeneous class of fishermen, intelligent and helpful, using the same methods, speaking the same language, and operating on the same banks. It was able to obtain from these fishermen records that brought to light the story of the fishery and the banks from the beginning and to create a statistical system of observation for the future.

The story could not have been uncovered without a scientific method of measuring the changing abundance and the changing intensity of the fishery. This can be best done by comparing the yield of a definite unit of gear from year to year, and by following the number of such units used. In many of the great fisheries of the world the gear differs greatly from vessel to vessel, and undergoes with time a gradual but great change in structure and efficiency, so that it is of little use in judging what has happened. But in the halibut fishery of the Pacific the gear has been much more constant and better standardized. It is a long bottom line on which are fastened short lines approximately 5 feet in length, set 9 or 13 feet apart. Each of these short lines carries a single hook, baited usually with herring. The whole, called a "skate" or "string of skates", is set on the bottom in depths of 50 to 175 fathoms. There were, of course, some problems connected with the relative efficiency of hooks according to their size, as to whether they were 9 or 13 feet apart and on heavy or light line. But these problems of standardization were readily solved, giving a sufficiently reliable unit of effort in the set of a unit of line a certain number of fathoms long. The fishermen themselves kept and used records of its yield for the purpose of gaging the results of their operations. These records as to catch per unit of effort had from the beginning

of the fishery been kept in the log books of the captains, enabling the catch to be analyzed according to the bank of origin. In the offices of the Commission they were collected and sorted according to nearly 40 areas, each embracing 60 miles of the trend of the coast. Records were obtained for as early as 1906, but, of course, they were much more complete for the years subsequent to 1925 when the Commission began its work. It is believed that since that time the records are more complete than for any other fishery.

Early records showed that when the first transcontinental railroad had thrown the markets of the eastern United States open to our western fishermen, the whole of the yield had come from a relatively small area within 500 miles to the north of the landing ports of Vancouver and Seattle. From this small area the total reached a maximum of about 60,000,000 pounds in 1912. But this great yield was only obtained by a disproportionate growth of the fleet, because the return per unit was continually falling. From 300 pounds per unit in 1906, the returns had fallen to 50 in 1926 and to 35 in 1929. The expansion of the fleet for the time masked this decline in abundance, but after attaining the maximum the total yield began to fail with the return per unit and in 1926 had reached a level of about 26,000,000. The original sources had failed under the strain. Not merely had the tremendous expansion of the fleet failed to increase its yield permanently, a serious economic matter in itself, but had caused it to fall to 45 percent of its maximum; and the abundance was steadily falling when the Commission took up its work.

In the meantime, however, the fleet had been undergoing great changes in efficiency and economy. The market demanded and the fleet furnished nearly as great a yield as ever, but to do so new boats were built capable of going farther and tapping new stocks of halibut on new and more distant banks. Many mechanical improvements were made, so that not only could vessels continue to fish on the depleted halibut banks but could go great distances, complete their catch in a short time, and return without prohibitive expense. The whole story was a vivid illustration of the application of power as our scientific age has developed it and made it available. The outstanding events were the adoption of gasoline engines in 1906 and of Diesel engines in 1921. But other seemingly less important things were vital. Electric lights permitted a 24-hour day on the fishing banks. Power lifted steel anchor cables and hauled the fishing lines themselves. Many other improvements were made, each contributing its bit to the expansion of the fishing grounds and to the operation at a lower level of abundance on the older grounds.

The result was a maintained total catch, hiding successive depletions of bank after bank, until the yield that came originally from

an area of 500 miles was stretched over 2,000 miles of coast from Oregon to Bering Sea.

Such a process of continued expansion did not have any limit in the early days. It seemed as though the fisherman could count on a continual increase in the efficiency of the vessels and on the existence of new banks to which he could resort as long as this efficiency permitted him. Depletion could be continually balanced by expansion. The industry was dependent not on what machinery it possessed but upon the constant addition to that machinery.

But the fisheries of the sea are not inexhaustible in extent, and in none of the great fisheries has this recently been so clear as in the case of the halibut. It is possible to show that the commercial fishery has extended into almost every extreme of the distribution of the halibut.

One of the steps taken by the Commission was to study the occurrence of halibut throughout the world in correlation with its environment, because this seemed to define the distribution.[2]

For many years scientists had been collecting data on the currents of the ocean and the temperatures of the waters; indeed, better records were available for such things and for the distribution of many smaller animals and plants than were available for the halibut. Nevertheless, by careful inquiry the distribution of halibut was plotted with sufficient exactness to show that it was taken in waters where the temperature was largely between 3° and 8° C. Whether temperature is the important factor is not yet known, but at all events it is either temperature or associated physical conditions.

The distribution of waters of these particular temperatures, and hence of the halibut banks, is a rather remarkable one. In the Atlantic the cold Arctic water meets the warm Atlantic water in the passages lying between North America and Greenland, between Greenland and Iceland, and between Iceland and the Faroes. And the warmer water follows the right-hand, eastern, side of the Nor-

[2] The halibut had until 1904 been regarded as a circumpolar species, common to Atlantic and Pacific. In that year P. Schmidt described the halibut of the Okhotsk Sea (specimens from Aniva Bay, Sakhalin Island) as a distinct species, *Hippoglossus stenolepis*, distinguished from the Atlantic halibut, *H. hippoglossus* (Linnaeus), by narrower scales, the manner in which they are set in the skin, the number of fin-rays, and general shape of the body. In 1929 he (U. S. S. R., Acad. Sci., C. R., ser. A, vol. 8, pp. 202–208, 1930) compared specimens from Japan, Bering Sea, and Vancouver Island, and stated that they were identical with *H. stenolepis* and distinct from the Atlantic form.

Somewhat more recently Hialmar Rendahl (Ark. Zool., vol. 22, no. 18, pp. 17–65, Stockholm, 1931), examining a specimen from Petropawlowsk, Kamchatka, in comparison with four specimens from Bohuslän, Sweden, expressed the opinion that it was intermediate between the Atlantic halibut, *Hippoglossus hippoglossus* (Linnæus) and *H. stenolepis* Schmidt, and he termed it "*H. hippoglossus camtchaticus*."

In view of the existence of races of halibut in the Pacific, and presumably in the Atlantic, which vary greatly in body proportions and other characters, it is not surprising that halibut from the two oceans differ. The exact significance of these differences and their magnitude as compared to the variation within either ocean is a subject deserving of further investigation.

wegian Sea. Currents flowing through these passages are deflected to the right by the revolution of the earth, a current as a rule following the right-hand shore, whether it is passing north or south. The water passing to the north warms the right-hand, or eastern, side, and there temperatures at which the halibut can live prevail; whereas on the western side of each passage the cold currents pass south, and temperature falls so low as to prevent its occurrence. There is, therefore, across the Atlantic a zone or belt of halibut banks tending to lie on the eastern side of each passage wherever currents of the warm Atlantic waters penetrate and touch continental shelves. They were found on the eastern side of Davis Strait between America and Greenland, the southern and western side of Iceland, near the Faroes, and on the Norwegian coast, and even in the Barents Sea where it is warmed by a branch of the Gulf Stream pressing to the right around the North Cape of Norway.

In the Pacific the Commission found the same temperature relationship. The bitterly cold waters of the Okhotsk Sea and the northern Bering Sea prevent the occurrence of halibut in numbers. On the Asiatic side the warm northward-flowing Japanese Stream approaches closely to the Arctic waters of the Okhotsk, and in the short stretch of coast line opposite the Island of Hokkaido, where the transition from cold to warm occurs, the halibut finds suitable waters lying above 3° C. Passing to the eastward over the North Pacific, the Japanese Stream is continued by the wind currents, rendering temperate the long coast line between California and Bering Sea. There 2,000 miles of coast line have bottom temperatures between 3° and 8° C., and in accordance with the size of this great area a great fishery exists.

Curiously enough, this distribution corresponds closely to that already found by the biologists for certain small invertebrates, which they call boreal organisms, living in the tempered water between the Arctic and Atlantic Oceans.[3] The halibut may therefore be called as boreal fish, if its occasional occurrence far outside its normal range be ignored.

Because of this distribution and its limitation by the physical conditions of the ocean, it has not been possible to find new banks indefinitely. There came a time when the increase in efficiency and the ability to travel great distances brought the fishermen to the natural limits of the halibut distribution. In the Atlantic this development culminated in great mother ships, with their own cold storages and fleets of small boats. They could remain at sea for long periods, independent of the shore and able to exploit the most distant

[3] Broch, Hjalmar, Einige Probleme der biogeographischen Abgrenzung der arktischen Region. Berlin. Univ. K. Zool. Mus. Mitteilungen, Bd. 19, 20 p. The Museum, Berlin, 1933.

banks. On the Pacific coast of America there remained but the southeastern edge of Bering Sea, which vessels have already entered, to find of doubtful value.

The waters into which commercial fishing had extended and over which the Commission had jurisdiction, therefore, formed a more or less natural unit outside of which no great supply could be expected. Connecting the Pacific coast of the United States and the small area of halibut banks on the Japanese coasts are two chains of islands, the Aleutians and the Kuriles. Along these the banks are narrow, quickly deepening, so that but few halibut can be expected. Connecting the Pacific coast and Bering Sea are the narrow passes through the Aleutians at the end of the Alaska Peninsula. Through these there cannot be expected any extensive migration of halibut. The coast line from California to the Aleutians seems, therefore, to comprise a natural unit of distribution. Within this distribution the supply must reproduce itself.

Yet within this the Commission found that it was not dealing with one stock of fish. That much was hinted at by the fact that each bank could be depleted in turn. The Commission demonstrated the existence of different stocks by several different types of research.

The first was by scientific experiments in marking. Halibut were caught by research vessels, tagged with numbered metal strips on the cheek bones, and liberated, and rewards were offered for their return when caught by the commercial fishermen. (Pl. 1, fig. 1.) Nearly 13,000 of these fish were marked throughout the whole extent of the fishing banks. The returns indicate that the immature smaller fish, on the average under 12 years of age, migrate very little. They seem to mill around inside the bounds of their native banks. When maturity is attained, these fish become more migratory, but they still remain within certain districts. Thus the mature fish tagged on the eastern side of the Gulf of Alaska on the famous spawning grounds called "Yakutat Spit" and "W Grounds" moved freely westward as far as the entrance to Bering Sea; but rarely southward. Other stocks of fish collected for spawning at various points along the banks to the south and during the summer scattered to adjacent feeding banks. But so intense had been the fishery on these older southern banks that very few mature fish were left. The great majority of fish were immature and stayed strictly at home, forming as many stocks of fish as there were banks. But on these southern depleted grounds conditions were so similar that the various banks could be grouped as one from the viewpoint of the regulation needed.

Occasionally tagged fish travel great distances. Tags placed on fish at the entrance to Bering Sea were sometimes recovered 1,500

miles away, off the coast of Washington. But these exceptions were so few as not to upset the general conclusions.

The findings were checked by other methods. For instance, that used by the anthropologist to distinguish races was applied. Thousands of fish were carefully measured, and physical characters such as length of head were found to differ from bank to bank. And, again, comparison of the rates of growth showed them to be very different on different banks. It was apparent that these peculiar characteristics could not have persisted unless the stocks had been isolated, at least during the growth of the individuals.

When these stocks of fish had been properly distinguished, it became possible to separate into proper units the splendid statistics gathered by the Commission as to the yield of the fishery. Those for each separate stock of fish could be combined and analyzed. Where before the steady increase in the number of stocks utilized had masked the changes occurring, and where before contrary tendencies in two stocks had balanced and obscured each other, now it could be seen that the yield in each individual stock was behaving in an orderly consistent way.

So well defined and simple were the laws governing the behavior of these stocks that it was possible for the Commission to understand what was happening on the banks. Knowing the intensity of the fishery it could reconstruct the course of events with sufficient accuracy to provide a forecast from year to year and to point decisively to the type of regulation necessary.

But these laws that seemed now so apparent were simple only when certain biological facts were known. In the first place, the age had to be known accurately, because the age is a time scale according to which the great changes in the fishery progress. Removal by fishing, death, or emigration takes place at certain variable rates, annually, and each age class as it enters the stock is decimated and finally disappears in accord with these rates. Its age represents the time during which these rates have been operating. In the second place, these rates of death, of growth, and of migration had to be known. The two categories of facts, time or age and rate of change in vital processes, are essential; age in itself is of little significance.

The age and rate of growth were determined by fascinating methods developed in recent years and around which a large body of scientific literature has grown. Many of the harder parts of the fish grow by addition to what has already been formed. Thus in the scales new growth occurs around the margins month by month during the year. Rapid growth is shown by a structure different from that of slow growth. As in the case of trees, fish undergo changes in their rates of growth according to the season. They are cold-blooded and change temperature and rate of metabolism with their

surroundings. Growth in winter may practically stop. Hence summer and winter zones, strikingly similar to those of trees, are developed. Under the microscope these can be read on the scales like those of a tree. In the halibut the scales are small and difficult to read. A much clearer picture can be obtained by using the otolith, or ear bone. This is a calcareous secretion formed in a sac of the internal ear of the halibut at the base of the semicircular canals, which somewhat resemble those of man. The crystals of calcium carbonate are laid down in definite summer and winter patterns with a differing content of organic matter, so that summer zones are opaque and white, winter zones translucent. In a large halibut this otolith may reach a length of approximately an inch and can readily be preserved to be read under a microscope or lens (pl. 1, fig. 2).

It was found that although halibut grow to a large size they take long to do it. Males grow much more slowly than females, the largest never exceeding 40 pounds; the largest females commonly reach 150 or 200 pounds and occasionally 350 or 400 pounds. Growth is very different on different banks. In the colder waters to the north and west a fish grows much more slowly. Usually a female is 12 years of age before it attains maturity and becomes a migratory spawning adult. Extreme ages of 25 or 30 years and over are attained. In fact, at the greater ages the growth of the otolith is so small that there is difficulty in reading it.

The Commission was thus able to separate the commercial catches into the different ages, finding that the numbers diminished with great rapidity as the fish grew older. The reason for this became apparent when the tagging experiments were analyzed. The returns from these indicated that the stock of fish was disappearing at about 60 percent yearly and that as nearly as could be made out 40 percent was due to the fishery itself. These rates of removal by the fishery and by natural death were very different according to area. It was estimated that on the western grounds about 12 percent annually was removed by the fishery, instead of the 40 percent on the southern grounds.

The stock, insofar as it was independent, could be affected only by these rates of death or removal and by the rate of growth as a balancing factor. On a depleted bank, with a corresponding excess of food and a temperature that fluctuated but little, growth seemed unlikely to be variable. No evidence of this appeared from the age determinations. The natural death rate might well be fairly constant also in a fish the size of the halibut. This would leave as a variable only the intensity of the fishery, with its corresponding fishing mortality. An attempt to connect fishing mortality with the yield of the fishery and the size of the stock left on the bank seemed therefore in order. It succeeded to such an extent that the major

changes in the fishery and the stock were explained, and a forecast could be made from year to year of what any given amount of fishing would yield.

So important is the principle involved that a careful review will be well worth while. It will be of interest to all biologists interested in population studies.

The explanation of how fishing intensity affects the stock is clearest when the changes in a single age group of young are followed in a series of hypothetical cases. A thousand young fish, coming on the banks as 5-year-olds, may be chosen and their fate under natural conditions followed. Natural mortality is not, perhaps, very high, but, for simplicity's sake, it may be assumed to be 20 percent.

Column 1 in table 1 represents the survivors in successive years, the calculation being carried for but 6 years in the interest of brevity. The weights at different ages are assumed ones, for the sake of clarifying the illustration. The true ones are given in table 4.

In column 2 are given the average weights at successive ages if growth is rapid enough just to balance the death rate, and in column 3 the resultant total weight of the group available in successive years if natural mortality alone were operating. From this it is seen that the fishermen who might take this group in its tenth year would get as great a poundage as though they had taken it in its fifth. In columns 4 and 5 a growth rate less than sufficient to balance the deaths is supposed. In such a case the fishermen would lose a large poundage by waiting. In columns 6 and 7, a third case, in which growth greatly exceeds loss by deaths, is shown. Delay in this case would greatly profit the fishermen.

It is plain that the balance between growth and natural death determines whether it is profitable to take the fish early or late in life.

TABLE 1.—*Hypothetical illustration showing how balance between growth of fishes and natural death rate determines whether it is profitable to take them early or late in life*

Age	Survivors (mortality 20 percent)	Growth to balance 20 percent mortality		Growth equaling half the loss by death		Growth equaling twice the loss by death	
		Average weight	Total weight	Average weight	Total weight	Average weight	Total weight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
5 years	1,000	4.00	4,000	4.00	4,000	4.00	4,000
6 years	800	5.00	4,000	4.50	3,600	6.00	4,800
7 years	640	6.25	4,000	5.06	3,240	9.00	5,760
8 years	512	7.80	4,000	5.70	2,916	13.50	6,912
9 years	410	9.77	4,000	6.40	2,624	20.23	8,294
10 years	328	12.20	4,000	7.20	2,362	30.34	9,953

TABLE 2.—*Poundage of fish stock surviving each year from a 90-percent annual catch (see p. 372)*

Year	Class A (born 1895) (1)	Class B (born 1894) (2)	Class C (born 1893) (3)	Class D (born 1892) (4)	Class E (born 1891) (5)	Total present in each year (6)
	Pounds	*Pounds*	*Pounds*	*Pounds*		*Pounds*
1900	4,000	400	40	4	+	4,444
1901	400	40	4	+		
1902	40	4	+			
1903	4	+				

TABLE 3.—*Poundage of fish stock surviving each year from an 80-percent annual catch (see p. 372)*

Year	Class A (born 1895) (1)	Class B (born 1894) (2)	Class C (born 1893) (3)	Class D (born 1892) (4)	Class E (born 1891) (5)	Class F (born 1890) (6)	Class G (born 1889) (7)	Total present in each year (8)
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*		*Pounds*
1900	4,000	800	160	32	6	1	+	5,000
1901	800	160	32	6	1	+		
1902	160	32	6	1	+			
1903	32	6	1	+				
1904	6	1	+					
1905	1	+						
1906	+							

TABLE 4.[1] *Rate of growth of Goose Island male and female halibut*

Age	Male		Female		Male and Female	
	Length	Weight	Length	Weight	Length	Weight
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*
4 years	21.7	4.0	22.2	4.2	21.9	4.1
5 years	23.2	4.8	24.2	5.5	23.7	5.1
6 years	25.0	5.9	26.4	7.1	25.5	6.2
7 years	26.6	7.1	28.3	8.8	26.6	7.6
8 years	28.3	8.8	30.3	11.0	28.8	9.4
9 years	29.9	10.6	32.5	13.4	30.6	11.3
10 years	31.7	12.4	34.4	15.9	32.8	13.7
11 years	33.5	14.5	36.4	18.9	34.4	15.9
12 years	35.0	16.8	38.4	22.2	35.7	17.9
13 years	36.8	19.6	40.5	26.2	37.8	21.4
14 years	38.4	22.2	42.5	30.2	40.4	26.2
15 years	40.1	25.3	44.5	34.8	42.6	30.7
16 years	41.7	28.5				
17 years	43.5	32.5				

[1] From H. A. Dunlop, unpublished manuscript. Measurements are average.

Let us now take the first case, in which the two balance. The fishermen might take their 4,000 pounds all in any one year, but as a matter of actual practice they do not; they take but a certain percentage annually. Yet, since the decrease in numbers is balanced by growth, they ultimately secure the full 4,000 pounds from each year class of fish.

If, for the sake of brevity of treatment, we suppose the fishermen to take the fish at a high rate, 90 percent annually, the poundage of the stock surviving each year would be as in column 1 of table 2. But at the time this class was 5 years old the next older age class would have been reduced to 400, as shown in column 2, the next older to 40, etc. And there would be 4-year classes present on the banks, totaling 4,444 pounds.

If, however, the fishery were less intense, say 80 percent annually instead of 90 percent, the same calculation will show that the taking of the 4,000 pounds would be spread over 6 years instead of 4, and that there would then be 6-year classes present on the banks, totaling 5,000 pounds. (See table 3.)

Yet in both of these cases the fishermen would get 4,000 pounds from each age group, and their catch from all the age groups present would total 4,000 pounds each year. *But the amount of fish left on the bank would be greater under the less intense fishery, and they would reach a greater age.* This would mean that the less intense fishery would catch as much as the more intense, yet would allow more fish to reach spawning size. (Incidentally, in halibut, eggs are produced approximately in proportion to weight.)

Of course, had the growth exceeded the loss by death, the fishermen would actually have *gained poundage* by a less intense fishery, because it would allow a greater growth. And, on the other hand, had growth been less than loss by death the fishermen would have lost poundage even though the amount of fish reaching spawning size had been greater.

These are simplified cases. Under an intense fishery, such as existed in the southern halibut banks, only the younger age groups are present in any numbers. Among such ages growth seemed to equal or even exceed the loss by death, as nearly as our estimates could indicate. Had the fishery been much less intense, and had the fish survived to a much greater age as a consequence, natural deaths would have increased among these older fish and growth would have decreased. Hence, although it was fair to expect that in the depleted fishery a lessened intensity would either not reduce or would increase the yield and would increase the number of fish reaching spawning size, yet this rebuilding of the stock would ultimately produce a condition where natural deaths would outbalance growth and further reduction of intensity would become unprofitable unless the number of spawners was still too small.

This analysis was tested by theoretical reconstruction of the stock according to the estimated rates of growth and death, and according to the intensity of the fishery. The latter was determined by the number of units of gear set each year. The close correspondence

between these derived curves of yield and abundance and those actually obtained from our records was clear evidence of the correctness of the theoretical basis of the calculations (figs. 1, 2).

As an additional proof, regulation reducing the intensity of the fishery over a period of 4 years has given the results that would be expected. With the limit in pounds for each area unchanged, the amount of fishing has been greatly reduced and the abundance on the banks increased, in the case of the southern banks about 60 percent. In the present condition of the fishery it therefore seems reasonable to conclude that the abundance on the bank and the

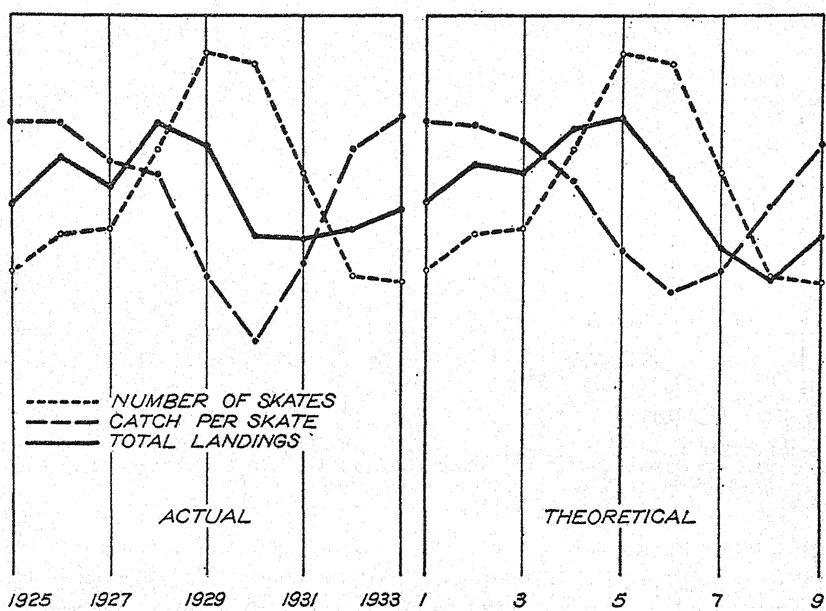


FIGURE 1.—Comparison between actual halibut yield and yield expected on a basis of theory, showing the total yield and the yield per unit for the grounds south of Cape Spencer, Alaska, 1925–33. A skate is a unit of gear, set once.

number of spawners can be increased at the expense of a reduction in the amount of fishing, very likely without loss of poundage, or even with a gain, until finally new supplies of young allow an increase.

In this consideration of the effect of the fishery upon the species, a very important economic fact has not been stressed. Throughout the history of the halibut fishery the intensification of the fishery has led to a reduction in the yield per unit. Where the total yield tended to be the same for the more and the less intense fisheries it can readily be seen why the yield per unit varied in reverse fashion to the number of units set. Even where the total yield was thought to have increased, this was not sufficient to obscure the decrease in

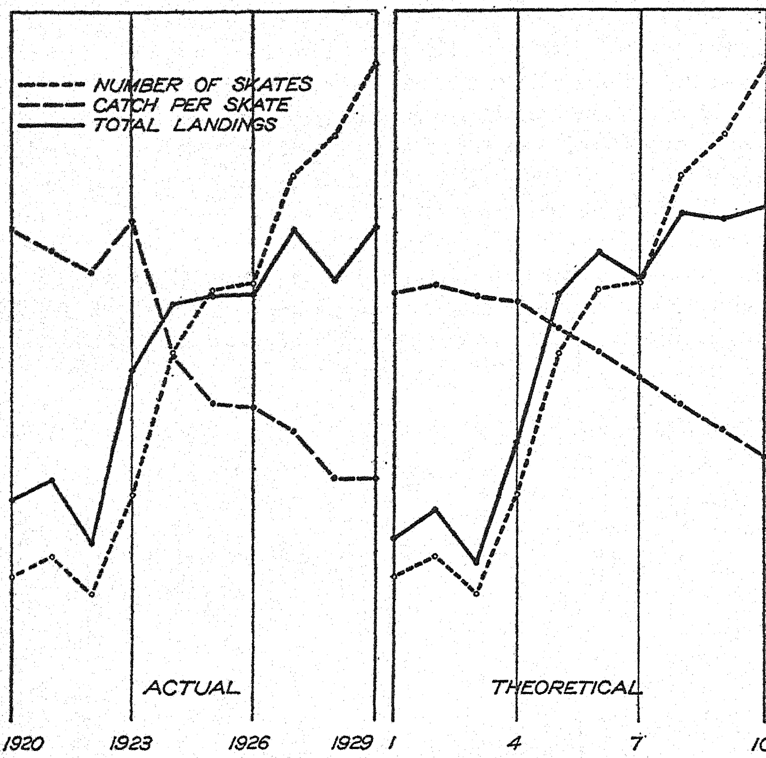


FIGURE 2.—Comparison between actual halibut yield and yield expected on a basis of theory, showing the total yield and the yield per unit for the grounds north of Cape Spencer, Alaska, 1920–29. A skate is a unit of gear, set once.

yield per unit. From the economic standpoint the decrease has been the only limit on the intensification of the fishery, the yield per unit being forced as low as would permit the fishery to exist, and the catch being produced from each bank at the greatest possible cost. The abundance on each bank therefore has sought an economic, not a biological, level, although the intensity of the fishery and the resultant mortality rate did have important biological consequences, as has already been seen.

Regulation of the intensity of the fishery should therefore have the important initial advantage of tending to correct a wasteful economic process—production of the catch at the highest possible cost and greatest effort.

The biological principle of this effect of fishing on the abundance is one whereby the Commission may increase the proportion of spawners, and hence of spawn. In addition, it may lead to a far more rational use of the existing supply, whereby the excess of growth over deaths can be taken advantage of, whenever and at whatever age it exists, to increase the total take. It leads to a defi-

nition of overfishing as of two types: (1) The poor use of the available supply by an intensity that takes fish too early and (2) the failure to leave enough spawning adults.

The Commission has seen in process the correction of the first type of overfishing. The existing records of catch per unit and of total catch might by themselves suffice to indicate whether the existing supply is being made better use of. But the matter is different with the second type of overfishing. It may require restraint where the first type of overfishing does not exist or where it has already been corrected. The records of total catch cannot prove or measure the increase in spawning adults, or the number of eggs and larvae these produce, or the number of the latter that survive to become young in the commercial catch. In fact, we know already from other species that the relation between these successive stages is not a simple one and that the increase may at some time reach its limit in any one of them. A slight decrease in the present high intensity of fishing should increase disproportionately the numbers of spawning adults, and hence of eggs. But the fishery may concentrate upon and destroy these adults, or natural mortality may increase as the average age is increased. It is, in fact, necessary to prove the fact that more young are produced and to correlate their numbers with changes in the production of spawn; or to show that these are now sufficient and need no increase.

Modern fishery science indicates that the high mortality due to fishing is in part balanced by the more favorable feeding and survival conditions which a sparse population encounters. These cause a decrease in the rate of mortality due to natural factors and an increase in the growth rate. Such changes constitute a "safety factor" which may be exceeded when fishing becomes too extensive. It may be the factor which has enabled species to survive great changes in natural conditions. Therefore, it is to be expected that a depleted fishery in which this safety factor has been exceeded has mortality and growth rates which are favorable to a greater production when changes in fishing allow a longer life. The limit to favorable regulation may in consequence be found in the reversion to normal of these rates as the stock on the banks is increased. Hence the necessity for constant observations of the results, however favorable they may now be.

These considerations have led to a program of measuring the halibut in the commercial catch to ascertain the changes in the numbers of adults and of young. Vessels whose catches are known to originate from banks chosen as typical are met, and as many halibut in their cargoes as possible are measured. The resultant data are analyzed statistically to show any increase in adults due to reduced

mortality, or any increase in young due to previously increased spawning. The most that can at present be said is that the changes seem to be those expected.

These considerations also have led to the study of eggs and larvae. This study is significant for two reasons: (1) Because these drift with the currents and may be carried from bank to bank (the existence and extent of this drift would greatly modify any regulations designed to increase the spawn if this came from areas other than those affected) and (2) because their abundance, as measured by the catch per net haul, should reflect the increase in numbers of adults. It is a more direct way of measuring this increase than the market measurements discussed above, because the commercial fishery may take varying percentages of the adults on the banks and is really what is taken rather than what is left.

The eggs and youngest stages of the halibut had never been described in the Atlantic despite the extensive work that had been carried on there upon the eggs and young of other forms. It is true that some of the older stages had been found, but in very small numbers. It was therefore with much satisfaction that the Commission was able to find an abundance on the western banks where depletion had not been as extensive (pl. 2).

By examining the catch of adults it was found that the spawning season is from the middle of December to near the last of March. The adult fish collect in schools at the edge of the continental shelf. These schools begin to collect in November, and at that time the fishermen find schools of males and of females migrating actively. Although these mature fish had become relatively scarce in southern waters at the time the treaty of 1924 became effective, because of the intense fishery there, they still existed in considerable numbers along the banks from the Gulf of Alaska west. There the egg of the halibut was found and described. It was one of the largest of the fish eggs found, being some 3¼ to 3½ millimeters in diameter. The eggs were laid at the edge of the continental shelf in depths of about 150 fathoms. They were then drifting freely with the currents, and by means of large, fine-meshed silk nets great numbers of them were caught. To work out their distribution and rate of development, hauls with these silk nets were made over a large part of the north Pacific between the entrance of Bering Sea and the coasts of Alaska and British Columbia. During one winter the vessel used logged over 10,000 miles. It was found that the young drifted with the ocean waters, developing slowly in much the same way that had often been described for flounders or soles. After hatching, the young transparent larvae swam upright, an eye on each side, as any normal fish should do. It grew steadily in depth of body until, in its fourth

or fifth month, color began to form, and the left eye began its migration to the other side. As development proceeded, the left eye assumed its usual place beside the other, and one side became densely pigmented. The young fish then settled in shallow waters or even in tide pools along the coast and became a replica of its parent, lying on its blind uncolored side.

Because of its long floating life, 5 or more months, water currents were the most important feature in the life of this young fish, and the Commission necessarily undertook studies of these currents, because in this remote corner of the Pacific very little had been done.

On the coasts of British Columbia and Alaska a great many glass floats or net buoys are found bearing Japanese characters. These, used by Japanese fishermen, are frequently lost and are carried by the Japanese current across the Pacific. The Japanese current on reaching our coast divides into two branches, one eddying to the north through the Gulf of Alaska, the other passing to the south and offshore into the influence of the California trades, which carry it to the Hawaiian Islands. The separation of the Japanese current into its two branches takes place at about the northern end of Vancouver Island in summer, south of the Washington coast in winter. It was studied by two methods.

One of these methods was by means of drift bottles, which carried within them a numbered card asking for their return to the commission. They were liberated off the coasts of Washington and British Columbia at the point where the Japanese current was expected to divide, and at various points in the Gulf of Alaska. An astonishing number of these bottles were recovered both from the Washington coasts and from the sparsely inhabited coasts of Alaska, showing clearly the currents and the great eddy that sweeps to the westward through the Gulf of Alaska in both summer and winter.

These indicated the surface currents only. Some other method had to be found that would prove that the deeper layers in which the young halibut were found were also moving. A method had been worked out by the Norwegians and applied by the International Ice Patrol over the Grand Banks in the Atlantic whereby the direction and speed of a current could be determined from a knowledge of the temperature, salinity, and dépth of the waters. The use of this method depends upon the fact that a current is deflected to the right by influence of the earth's rotation. Its speed and direction can therefore be determined by the internal distortion of the natural levels that the layers of more or less dense water would otherwise attain. These methods were applied in the Gulf of Alaska confirming the evidence of the surface currents as to the point of division of the Japanese Stream and the formation of a great eddy flowing westward through the Gulf of Alaska.

The work upon the temperature and salinity showed that the waters in this district increased in salinity with depth. The increase took place much more rapidly at about the level of the edge of the continental shelf. The adult halibut spawns on these edges apparently just within the layer of denser water, in depths of about 150 fathoms, and its young, hatching and drifting as transparent larvae, are carried by the currents in this denser water until the time metamorphosis approaches. At that time the young rise into the lighter surface water and into the more rapid currents there. It is still unknown just how far the young are carried. In the surface water they presumably drift inshore as well as alongshore, because shortly afterwards the young are found in shallow water and indeed along the beach.

Nothing in this early life history indicates that the young fish drift far enough to get out of the coastwise currents. The silk nets took them in great numbers immediately outside of the 1,000-fathom line and in but scattered numbers farther at sea. The direction of the currents and the distribution of the eggs and larvae were such as to make us certain that the young from the grounds of the Gulf of Alaska, however much they might contribute to banks further westward, could not contribute to those to the southward along the coasts of British Columbia and the State of Washington.

The picture is not yet a precise one. It is known only in its general features. The currents in deep water perhaps move much more slowly than we at present believe, and even in the upper layer of water it is entirely possible that the drift is such as to carry the young inshore rather than any greater distances along the coast or seaward. These are points which must be cleared up by further research. The work of the Commission has not yet been completed.

Spread broadcast in the sea as the eggs of the halibut are, it is understandable why such great numbers of them are produced. Although the halibut does not usually mature until about its twelfth year, nevertheless when it does mature it produces a great number of eggs. The eggs are large, but the fish is also large. A 12-year-old female may produce 200,000 to 500,000 eggs, depending upon its weight, a 20-year-old female may produce between 1,100,000 and 2,750,000, while some the the larger and older fish have been known to produce as many as 3,500,000. That number of eggs would seem more than a female could carry, but careful studies have shown that only small numbers are ripe at any one time. Before the last stage of ripening the eggs measured were approximately half a millimeter in diameter, but just before shedding became translucent and large and when shed averaged 3.25 millimeters.

These great numbers are produced because of the perils which the young meet during their drift in the sea. Depending as they do upon the currents, vast numbers of them must be swept to sea and lost simply because they do not reach the banks upon which they can develop. These losses would, of course, be additional to those caused by enemies.

Something like this must happen to the halibut at the southern extreme of the range, off the coasts of Washington and Oregon. There at one time a very large stock of halibut had accumulated, but the fleet, having discovered them, concentrated upon them and in 2 years had so reduced them in numbers that only a small fishery could be carried on. The fishery has never recuperated and has supported but few vessels annually since that time. Apparently the powers of recuperation there are small, and it is noteworthy that in that district the winds are offshore. The currents may be either south or offshore so that the young may indeed be lost in very great numbers.

The life history of the halibut in the light of what has been discovered may be summarized as follows:

The halibut along the Pacific coast may be divided into several different stocks, that inhabiting the Gulf of Alaska and westward being fairly distinct from those to the south. In this stock the adult fish migrate freely between the entrance to Bering Sea and Cape Spencer on the east. Spawned after an eastward movement the eggs and larvae drift slowly in the deeper water for a period of 4 or 5 months. Then they rise into the upper layers of water to be deposited inshore and along the coast where they undergo their metamorphosis to small halibut. As such they remain on the bottom until they reach maturity. This is reached on the average in their twelfth year when they resume the migrating habits of the adult.

This stock of halibut in the Gulf of Alaska and westward, therefore, has its being in the giant water eddy which is characteristic of that region. It does not inhabit the coast of Alaska as much as it does the Alaska Stream, or eddy.

To the south mature fish are so lacking that neither the eggs and young nor the adults can be studied with any exactness. Although it is known that several distinct stocks of adult fish exist there on grounds known to the fishermen as spawning banks, yet the extent to which the young drift has not yet been demonstrated. In the last year, under the regulations of the Commission, the stock of adults has shown a distinct increase, and it has been possible to begin a study of the eggs and larvae in one of these stocks, that off Cape St. James at the southern end of the Queen Charlottes.

Exact studies are being made of the depths at which the halibut eggs float, and a more exact examination of the currents and their rate of flow is also under way. Judged from the consistency in the distribution of the eggs and young already found, it may well be that the deeper waters here do not move any great distance during the time of the development of the young halibut. That, however, remains to be shown. Plainly the currents and physical conditions must be known before the characteristics of each stock can be made out with any certainty.

From all these facts regulations have been devised separating the coast into areas, limiting the intensity of the fisheries in each area, and closing nurseries and spawning seasons. On the walls of the Commission laboratories are kept charts showing the changing abundance of the halibut in its different areas; the great decline in abundance from the earliest days until the year 1930 is shown; where once 300 pounds of fish were taken on the standard unit of gear it is shown that on the southern grounds the yield had fallen to 35 pounds and on the western to 65 pounds, while the total catch on the southern grounds had fallen from 60,000,000 to 22,000,000. The Commission was organized in 1924. Under the observation of its staff the later part of this decline from 1925 to 1930 occurred. At that time the Commission had no powers of regulation. It could merely study and analyze, but in 1930 it submitted recommendations to the two governments, and a new treaty was adopted giving the Commission proper regulatory powers. The result is shown on the charts kept by the Commission. Beginning with 1931 the abundance has risen steadily on the banks to the south from 35 pounds to 60; on the banks to the west from 65 pounds to 90. The Commission has made good use of the scientific instruments placed at its disposal by its staff.

Perhaps the most crucial part of this great experiment in conservation is still to come. Its final success depends upon whether the character of its results thus far will be clearly understood and whether the economic readjustments to increased abundance can be made.

The increased abundance of fish on the banks is somewhat difficult for the fisherman to understand. He cannot see why since there are more fish he should not be permitted to take more. He does not realize at first that the increased numbers of fish are due to the greater proportion which the Commission has allowed to survive by reducing the intensity of the fishery. He does not realize that under present conditions he is taking a smaller proportion of each year class of halibut but that in recompense a greater number of year classes has come into being. From all of these year classes

he is getting as great a total as before but the amount of fishing gear he can run has had to be reduced in order that the proportion of each age class would be less. As a result, the greater proportion of these age classes which has been allowed to survive each year has tremendously increased the number of spawning adults.

The fisherman should welcome effective conservation whereby he is able to take his catch with greater ease and in a shorter time. It would seem a small price to pay for an ultimately greater number of incoming young, but so complicated is our economic machinery that difficulties have been met with. Even though the total catch has not been reduced the existing fleet has been able to land the total allowed by the Commission in a short period of time. Where before, 9 months were required, now but 5 are necessary. The halibut, however, are largely desired fresh for the market. If landed within such a short period a larger proportion of the catch must be frozen. To remedy this, the fleet has sought to spread the catch over the usual period of time to prevent it becoming a seasonal fishery. It is apparent that our economy must be modified to accommodate restraint in production.

It may seem to the fisherman somewhat like magic; that by fishing less he can obtain as much or more from the sea than before. But to the Commission, interested in increasing the number of young, as well as making better use of what we have, the results are profoundly interesting. They see the commercial catches becoming to a greater extent composed of mature spawning fish. They see the number of floating eggs and larvae increasing, and they await with eagerness the time when these increased young commence to show in the commercial catch as a real increase of the available stock, an increase that may be used, not simply an accumulated reserve. Justifying each step by its practical success, a great biological experiment is in progress, testing the ability of men to perpetuate and exploit rationally the vitally important resources of marine fish.

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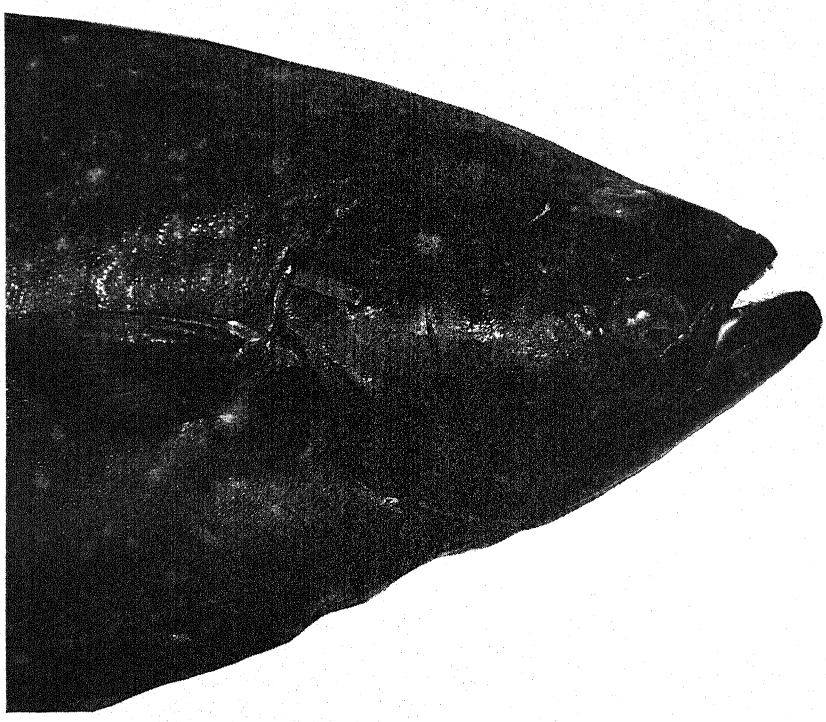
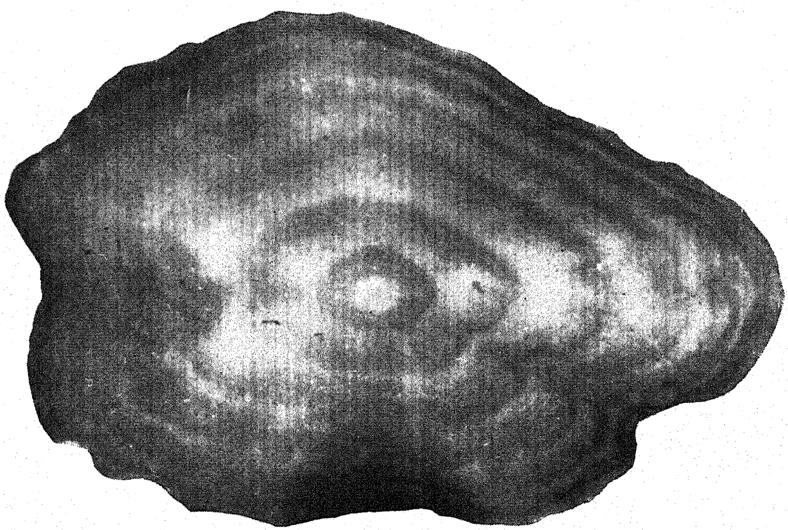
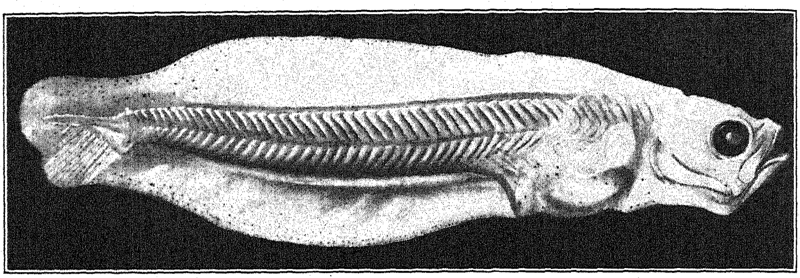


Halibut with numbered metal tag on cheek bone. A reward is offered for the return of such tags by fishermen.

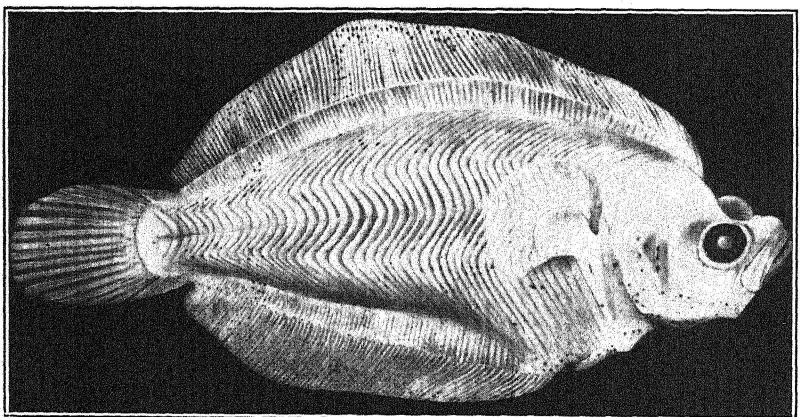


Halibut ear bone or otolith from a seven-year-old fish showing concentric rings by which age can be read.



Drawn by Jessie W. Phillips.

1. Halibut larva 15 millimeters long with eyes on opposite sides of the head.



Drawn by Jessie W. Phillips.

2. Halibut larva 19.5 millimeters long with left eye in process of movement to the right or colored side.

THE SWALLOWTAIL BUTTERFLIES

By Austin H. Clark
United States National Museum

[With 14 plates]

INTRODUCTION

Most generally familiar of all the various types of butterflies to those who live in the tropical and temperate regions of the world are the so-called "swallowtails." In very many places they are the most conspicuous of all the insects—indeed the most conspicuous of all the forms of animal life except the birds.

Alfred Russell Wallace wrote that the swallowtails occur in the greatest profusion in South America, northern India, and the Malay islands, and here they actually become a not unimportant feature in the scenery. Particularly in the Malay islands the giants of the group, the great "bird-wings" or ornithopteras, may frequently be seen about the borders of the cultivated and the forest districts, where their large size, stately flight, and gorgeous coloring render them even more conspicuous than the generality of birds.

Sir Joseph Hooker, in his Himalayan journals, says of the swallowtails in India:

> By far the most striking feature consisted in the amazing quantity of superb butterflies, large tropical swallowtails, black, with scarlet or yellow on their wings. They were seen everywhere sailing majestically through the still hot air, or fluttering from one scorching rock to another, and especially loving to settle on the damp sand of the river edge; where they sat by thousands, with erect wings, balancing themselves with a rocking motion as their heavy sails inclined themselves to one side or the other, resembling a crowded fleet of yachts on a calm day.

Nearly all the swallowtails are large, and not a few are very large—in fact, the largest of all the butterflies are members of this group. Most of them are marked with strongly contrasting colors—black or dark brown with white, red, yellow, blue, or green, or two or more of these in combination—and many have iridescent or metallic spots, or patches of metallic scales. Some have the upper surface of the wings largely, or even almost wholly vividly

metallic, shimmering gold or golden orange, purple, green, or blue, or two or more of these together, such lovely kinds being perhaps the most magnificent of all the butterflies.

The swallowtails are especially to be found in more or less rugged regions—hilly or mountainous country—where they haunt the borders of woodlands and the nearby fields and gardens, or the roads and glades and clearings in the woods. Many like rough and more or less open, scrubby country, while some prefer low-lying open fields or even the gloomy recesses of swamps. Rocky exposed hilltops, both in woodlands and in open country, are everywhere a favorite playground for them.

Each of the different kinds of swallowtails has its own special preferences, which are not quite the same as those of any other kind; but some are much less difficult to suit than others. For instance, our common yellow swallowtail (*Papilio glaucus*, pl. 8, fig. 30) lives both in woods and open country, in lowlands as well as in the mountains, from Alaska east to Hudson Bay and southward to Florida and the Gulf of Mexico. Our common black parsnip swallowtail (*Papilio polyxenes asterius*, pl. 12, fig. 59), on the other hand, is an open country, chiefly lowland butterfly and will not enter woods, while the spicebush swallowtail (*Papilio troilus*, pl. 11, fig. 49) and the palamedes of the South (*Papilio palamedes*, pl. 11, figs. 47, 48) prefer the woods, especially wet low-lying woods, and will not stray far from them.

Very nearly all the swallowtails are strong upon the wing. The larger usually have a leisurely, more or less sailing or gliding flight that is often much swifter than it seems to be. This type of flight is seen in our giant swallowtail (*Papilio cresphontes*, pl. 9, fig. 37). The smaller swallowtails for the most part have a fluttering, nervous flight which in some is very irregular, in others direct and very swift. This nervous, erratic flight we see in our common black parsnip swallowtail (*Papilio polyxenes asterius*, pl. 12, fig. 59) as we watch it dashing about over the clover fields, and in the even more impetuous flight of the large summer males of the blue swallowtail (*Papilio philenor*, pl. 11, fig. 53). In some of our swallowtails the small individuals of early spring, found chiefly in the woods, have a fluttering and active flight that is more or less widely different from the flight of their much larger summer children, living largely in the open. We notice this in the yellow (*Papilio glaucus*, pl. 8, fig. 30) and the zebra (*Papilio marcellus*, pl. 13, fig. 78) swallowtails.

Mainly tree-top butterflies, flying strongly, swiftly, and very high, or sailing about the branches far above the ground, are the largest and most magnificent of the swallowtails, the ornithopteras or bird-winged butterflies (pl. 1, fig. 1) of the Malayan region.

Quite different are the habits of the smallest swallowtails—curious little creatures with largely transparent wings and very long tails (*Leptocircus*, pl. 1, fig. 2)—that are found in southeastern Asia and in the large Malayan Islands. According to Henry O. Forbes, these queer little butterflies flit over water fluttering their tails, jerking up and down just as dragonflies do when flicking the water with the tip of their abdomens. They mimic the habits of the dragonflies and are often to be found flying together with them. When they settle on the ground they are difficult to see, for their tails and wings are constantly in vibratory motion, so that a mere haze, as it were, exists where they are resting.

Perhaps more curious still are a few swallowtails of medium size that look much more like butterflies of other groups than they do like swallowtails. These have an awkward, clumsy flight like that of the butterflies they resemble.

All of the swallowtails are very fond of nectar and are therefore familiar visitors to gardens, where in certain places multitudes disport themselves about their favorite plants. When feeding on the flowers some of the swallowtails rest quietly with their bodies hanging vertically and the wings fully extended. This is the usual habit of the giant (*Papilio cresphontes*, pl. 9, fig. 37) and the yellow (*Papilio glaucus*, pl. 8, fig. 30) swallowtails. Others, like the parsnip (*Papilio polyxenes asterius*, pl. 12, fig. 59) and the spice-bush (*Papilio troilus*, pl. 11, fig. 49) swallowtails keep their wings more or less constantly in motion and the body horizontal or more or less inclined, but very seldom vertical. If you watch carefully a swallowtail fluttering on a flower—a parsnip or a spice-bush swallowtail—you will be surprised to see that only the fore wings are in motion; the hind wings are motionless and expanded, making with each other an angle from a right angle to an angle half again as great. The gorgeous ornithopteras when feeding, like the blue swallowtail (*Papilio philenor*, pl. 11, figs. 53, 54), their commonest representative in North America, always keep their wings in motion, and one long-winged kind living in the Malayan region (*Papilio brookeana*) moves its wings so very fast as to suggest a hummingbird.

All swallowtails fly only in the daytime, most of them only when the sun is shining. However, a few are very early risers. Among our native kinds the blue swallowtail (*Papilio philenor*, pl. 11, figs. 53, 54) is always the first to visit flowers in the morning and the last to disappear at night. In small numbers and in indolent fashion as if only half awake it begins to fly about shortly before sunrise, and a few are to be seen until nearly dark, competing with the hawk moths for the nectar from the flowers. The blue swallowtail is already feeding before the other swallowtails have begun the process of awakening, which usually consists in resting on some con-

venient leaf with fully expanded wings exposed to the direct rays of the early morning sun, and it is still feeding long after the other kinds have gone to sleep hanging from a leaf.

This habit of sleeping hanging from a leaf, common to most swallowtails, has the great advantage that escape for a large and none too agile butterfly is easy in case of an attack by enemies, either flying or tree-climbing creatures. But it has the disadvantage that if a wind arises, the insect will be blown against the neighboring leaves, and the outermost portions of the wings, the tails, and the adjacent portions of the hind wings, will suffer damage. The torn hind wings of swallowtails are evidence of the precariousness of their roosting places at night, not of attacks by birds.

Though relatively large, powerful, and swift, swallowtails seem to be almost entirely devoid of the exploring spirit. They do not indulge to any great extent in the migrations so characteristic of some other types of butterflies.

Only 18 kinds of swallowtails have been reported in migratory flight. In North America the giant swallowtail (*Papilio cresphontes*, pl. 9, fig. 37) and the spice-bush swallowtail (*P. troilus*, pl. 11, fig. 49) have once been reported at the end of August and early in September migrating at Point Pelee in western Lake Erie, together with that well-known wanderer, the common milkweed butterfly (*Danais plexippus*). But not infrequently stray individuals of various swallowtails may be found more or less far from their normal habitat. Thus I have recorded the zebra swallowtail (*Papilio marcellus*, pl. 13, fig. 78) from Boston, Mass., and it has also been recorded from Vancouver Island; the giant swallowtail (*P. cresphontes*, pl. 9, fig. 37) has been recorded from Maine and Nova Scotia, and I once caught one near Boston; and the southern magnolia swallowtail (*Papilio palamedes*, pl. 11, figs. 47, 48) has been caught at Philadelphia. However, such sporadic occurrences cannot properly be considered as evidence of true migration.

In British Guiana great numbers of a silky white swallowtail (*Papilio philolaus*) were once observed flying all in the same direction, mostly in a steady way, but a few resting here and there upon the ground. There are no other notices of swallowtail migrations in America.

It is curious that only the giant swallowtail (*Papilio cresphontes*, pl. 9, fig. 37) has been reported from Bermuda, although our small least sulphur (*Eurema lisa*) sometimes visits the islands in enormous numbers, and the yellow clover (*Eurymus philodice philodice*) and one of our wood-loving wood nymphs or satyrids (*Enodia portlandia*) are among the islands' 14 butterflies.

The common yellow swallowtail of Europe (*Papilio machaon*) appears to have had a migration in the north of France, in the

Channel Islands, and in the south of England in 1900. A small migration was reported near Bagdad, Iraq, in 1918 or 1919, and in 1872 numbers of individuals were observed about 5 miles from land off Monte Pellegrino, near Palermo, Sicily.

No swallowtail migrations have ever been reported from Australia or from Africa. No less than 11 different kinds, however, have been reported in migratory flight in southern Asia, chiefly about Ceylon and southern India; but there are two records from Siam and one from New Guinea.

Nearly all the records of oriental swallowtail migrations mention these butterflies as components, more or less important, of mixed flocks chiefly of white and yellow butterflies (Pieridae), often with relatives of our milkweed butterfly (species of *Euploea* and *Danais*) and various other kinds. So the swallowtails seem really to be home lovers that are sometimes led astray by their sociability, which induces them to follow along with other sorts of butterflies toward an unknown destination.

Only a single swallowtail (*Papilio hector* of India and Ceylon) has been reported with any frequency at sea, but this has been captured as much as 200 miles from land (Ceylon).

The lack of the exploring spirit in the swallowtails is accompanied by a similar lack of a belligerent attitude toward other living things. They are more peacefully inclined than the majority of butterflies. Live and let live seems to be their motto. Though they indulge more or less frequently in duels, the males as a rule do not display that spirited aggressiveness and zest for combat so characteristic of the males of many butterflies. Neither are they prone to bully other insects. They go about their own affairs with a calm disregard for other creatures.

Still, on occasion temptation may prove too much for them. I have seen a blue swallowtail (*Papilio philenor*, pl. 11, fig. 53) turn from its course to chase an English sparrow that rose from the grass, continuing the chase until the frightened bird was safe among the branches of an apple tree. Incidentally, from this incident I learned the speed of flight of the blue swallowtail. This butterfly has such an erratic flight it is impossible to pace it. But this particular individual followed the scared sparrow in a perfectly straight line. The speed of the sparrow was about 25 miles an hour, and that of the butterfly was the same.

It happens that the only insect I have ever seen attacked and routed by a fritillary is this same blue swallowtail. Once I was watching a pair fluttering about together about 3 feet above some milkweeds when a male of our largest fritillary (*Argynnis diana*) dashed at them, sending them scurrying off in opposite directions.

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SOME PECULIARITIES OF SWALLOWTAILS

In their general appearance the true swallowtails (*Papilio*) show great diversity, though in spite of their wonderful variety of form and color they are structurally all very much alike.

Most of the swallowtails have the hind wing produced into a tail-like process that may be long and narrow, short and broad, acute or spatulate, or even racketlike; a few have two or even three tails—one, indeed, possesses four. But some have merely a slight tooth where the tail ought to be, and many have the hind wings simply rounded with no trace of tails at all. The tail, when present, is stiffened and supported by the prolongation of one of the veins of the hind wing; in *Papilio elwesi* and two related forms occurring in western China and Formosa the unusually broad tail is supported by two veins.

In the majority of the swallowtails the sexes are almost or quite alike in form and in the color of their wings, but in many they are very widely different. The females are almost always larger than the males, usually slightly larger, but sometimes, as in *Papilio paradisea*, very much larger. Very rarely they are slightly smaller; in a single case, *Papilio antimachus*, very much smaller. Usually the males are more numerous than the females, and in quite a number the females are as yet unknown. In a few, as *Papilio priapus* and *P. sycorax*, the females are more numerous than the males. Usually both sexes inhabit the same territory, though the males are more active than the females, so that they are more frequently seen in gardens and in open country, and are more often caught. But in some kinds, as *Papilio aeneas marcius*, *P. sesostris sesostris*, and *P. vertumnus diceros* of the lower Amazon, the males are found in swampy shades and the females in more open places.

In some, as *Papilio paradisea* and *P. dardanus*, the males possess conspicuous tails, while the females lack all traces of them; and in others, as *P. memnon*, the males are tailless and some of the females have conspicuous tails. Some swallowtails, as *Papilio polytes*, *P. dardanus*, and *P. memnon*, have a varying number of different types of females, though only a single type of male. A few have several types of males but only a single type of female. Several, as our *Papilio bairdi* (pl. 12, figs. 55–57; pl. 13, figs. 67–70), have two or three or more different color types common to both sexes.

Widely ranging swallowtails always differ more or less from one region to another, and often are divisible into several or many different forms, especially if they range over the islands of an archipelago, or throughout the higher valleys of an extensive mountain system. Usually both the males and females show similar, or at least correlated, local variation, but not infrequently this local variation is only evident, or at least conspicuous, in the females, far more

rarely only in the males. One wide-ranging swallowtail in southern Asia, *Papilio polytes*, has 4 different types of females in one region, 3 in another, 2 in another, and in some places only 1.

It is a most curious fact that in many regions all the native swallowtails, in other regions the majority, or several, differ from the corresponding forms in adjacent regions in certain definite ways. Bates pointed out that species in three distinct groups which on the upper Amazon and in most other parts of South America have spotless fore wings acquire white or pale spots on the fore wings in the lower Amazon region and about Para. As was pointed out by Wallace, the swallowtails of Sumatra, Borneo, and Java are almost invariably smaller than the allied forms in the Moluccas and in Celebes. No less than 14 kinds in Celebes and the Moluccas are from one-third to one-half again as great in extent of wing as the corresponding forms in Borneo, Java, and Sumatra. The species in New Guinea and in Australia are also, though in a less degree, smaller than their closest representatives in the Moluccas. In the Moluccas themselves the forms found on Amboina are the largest. The forms on Celebes equal or even surpass in size those of Amboina.

Species that are tailed in India become tailless to the eastward on the islands of the Malayan archipelago. In America all except two of the very numerous *Aristolochia* swallowtails occurring between Costa Rica and southern Brazil are without tails, whereas nearly every species occurring from southern Brazil southward and from Costa Rica northward is provided with tails.

Almost every species of swallowtail on the island of Celebes has the fore wings more elongate and falcate than the corresponding forms elsewhere, with the anterior margin much more strongly curved and usually with an abrupt bend or elbow near the base.

In many swallowtails there is great individual variation. Most commonly this is confined to the females. Sometimes it is equally evident in both sexes, and rarely it is seen chiefly in the males. Variations may be of constant occurrence or sporadic. They may occur throughout the range of a species, or they may be confined to certain regions within that range. In *Papilio memnon* of eastern India and the Malayan region the females, which may be either with or without tails, are most extraordinarily variable in color and color pattern, except on the Riu Kiu Islands, where there is only a single type of female. Even more variable are the tailless females of the African *P. dardanus;* but in the form occurring on Madagascar the sexes are alike. In *Papilio clytia* from India and the Malayan regions both sexes are very variable. The dark forms show division into geographical races, but the light forms, though very variable, do not. In the Philippines and Palawan only the dark form occurs, and on

the Andamans only the light form. *Papilio paradoxus* from the Malayan regions is another species showing extreme variability. Among our own swallowtails *Papilio glaucus* (pl. 8, figs. 30, 31; pl. 10, fig. 41; pl. 12, fig. 65) is very variable in the female sex in the northern half of its range, *P. polyxenes* (pl. 12, figs. 59, 60) is variable in the male from Arizona and New Mexico southward, and *P. bairdi* (pl. 12, figs. 55–57; pl. 13, figs. 67–70) has widely different forms in both sexes.

In a number of swallowtails, particularly in eastern Asia and eastern North America, the individuals appearing in early spring are much smaller than, and more or less widely different from, summer individuals of the same species. (See pl. 13, fig. 78, and pl. 14, fig. 89.) In others in the Tropics there are more or less marked wet and dry season forms.

Strange aberrations of all sorts, some of rather frequent recurrence, are found in many species (pl. 9, fig. 40; pl. 12, figs. 61, 66).

WHAT IS A SWALLOWTAIL?

Many friends we recognize at once without appreciating just what it is about them that enables us to distinguish them from many other friends. It is the same with swallowtails. It is easier to distinguish them from other kinds of butterflies than to describe how it is you do it.

In the swallowtails all six legs are perfect and are used for walking in both sexes, and the longest joint (tibia) of the legs of the first pair bears near the middle of the inner side a leaflike appendage or epiphysis, as in the skippers (Hesperiidae). The head is large, but much less broad than in the skippers, and the bases of the antennae are close together.

Swallowtails are mostly large or very large, but a few are of medium size and a very few are small. The very small ones are all provided with enormously long tails.

They are found throughout the world except in the extreme north, in southernmost South America, in New Zealand, and in the highest altitudes in the Andes. They are especially numerous and varied in the Tropics, particularly in South America, northern India, and the Malayan region, including the larger islands of the Malayan Archipelago. The greatest variety of different types, however, is found in temperate Asia. On the other hand, Africa has the least number of different types, though the number of kinds found there is fairly large.

The largest local butterflies are swallowtails in every region of the world except in South America, where these are surpassed in size by some of the owl butterflies (*Caligo*) and the morphos. In-

deed, in the Western Hemisphere the largest of the swallowtails (*Papilio homerus*) lives not upon the continent, as would be expected, but upon the island of Jamaica and the most beautiful one (*Papilio gundlachianus*) is confined to eastern Cuba.

The numerous species of *Papilio* are divisible into three major sections, and each of these falls into numerous minor groups of greater or lesser value. These groups are known as the *Aristolochia* swallowtails, the fluted swallowtails, and the kite swallowtails.

THE ARISTOLOCHIA SWALLOWTAILS

The *Aristolochia* swallowtails are so called because their caterpillars feed only on the leaves of the Dutchman's pipe (*Aristolochia*) or closely related plants.

They are especially distinguished by their curious caterpillars. These when fully grown are stout, soft, and black in color, with on each segment from 4 to 6 fleshy tubercles or filaments varying in length according to the species, some of which may be orange or red. They are densely covered with minute hairs, which gives them a velvety appearance.

The butterflies themselves are very much less obviously different from those of the other sections than are the caterpillars or the chrysalids. But, though rather inconspicuous, their distinctive characters are of a fundamental nature. The antennae are not scaled, and to the naked eye they appear less distinctly jointed than those of the species in the other sections, as the segments are basally not markedly constricted or compressed. The bodies of the *Aristolochia* swallowtails are curiously soft, and on pressing the thorax, or portion between the wings, a yellow liquid oozes out from all the sutures, and sometimes even from the tips of the antennae. They are very tenacious of life and will recover from a pinch that will kill any species of the other sections.

In all the *Aristolochia* swallowtails the flight is direct, and in most cases low. Some have a rather rapid nervous flight, but the flight of most of them is clumsy, and in the larger oriental ones often quite awkward. All of them keep their wings in motion while feeding. They are unsuspicious, and most of them may easily be taken with the hand.

The species of this section seem all to be common where they occur, though many are very local. They live in and about the woods and forests, and are very frequent visitors to gardens. Wherever *Aristolochia* is grown as a cultivated plant they are quick to discover and to take advantage of it.

The *Aristolochia* swallowtails are found in North and South America, Asia, Australia, and Madagascar, but there are none in

Africa or Europe. They are especially abundant in the Tropics, and do not extend so far to the northward as do the fluted swallowtails.

In America none of the *Aristolochia* swallowtails are very large, and none are very striking in appearance. It is in southeastern Asia and thence eastward through the Malayan archipelago and southward to Australia that the largest and finest of these butterflies are found. Especially in New Guinea and on the surrounding islands they reach a size exceeding that of any other butterflies and at the same time a brilliance and diversity of color unsurpassed by any other butterflies elsewhere.

These gorgeous giants of the group have commonly been separated from the other swallowtails and treated as a special genus called *Troides* or *Ornithoptera* (pl. 1, fig. 1). But the differences between them and the other *Aristolochia* swallowtails are so very slight as to render such treatment quite impracticable. Excepting only for their larger size, their caterpillars and chrysalids are quite like those of the other species of the section. Several magnificent kinds are found only on New Guinea. Among these is the largest of all butterflies, the great *Papilio alexandrae*, of which the dingy blackish female measures slightly more than 10½ inches across the wings. The male, which has curious narrow rounded wings, is also very large, 8½ inches in expanse, and also very handsome, metallic green shading to metallic blue and marked with black.

In some of the *Aristolochia* swallowtails the males have a strong and pleasant odor. This is especially noticeable in the common *Papilio aristolochiae* of southern Asia, which because of its fragrance is known as the "rose-butterfly", and in *Papilio devilliers* of Cuba and southern Florida (pl. 11, figs. 51, 52), which is strongly scented with a delicious perfume resembling that of a fragrant orchid.

OUR NATIVE ARISTOLOCHIA SWALLOWTAILS

Ranging over most of the United States, but commonest in the southeastern section, where in certain regions it is the most numerous of all the swallowtails, we find the blue swallowtail (*Papilio philenor*, pl. 11, figs. 53, 54; pl. 14, figs. 82, 83). One of our very prettiest butterflies this is, though full appreciation of its beauty is often somewhat dimmed by its predilection for laying its eggs on Dutchman's pipe when planted as an ornamental vine about porches and verandas.

Much like this on the upper side, but very different underneath is another kind (*Papilio devilliers*, pl. 11, figs. 51, 52), an inhabitant of Cuba sometimes found in Florida.

In southern Georgia, southern Florida, Texas, Arizona, and southern California there appears, more or less irregularly, a related kind wholly without tails (*Papilio polydamas*, pl. 14, figs. 79, 80). This butterfly lives all over tropical America and as far south as Buenos Aires. In Florida, in addition to the typical form, there is also found the variety (*lucayus*, pl. 14, fig. 81) whose proper home is the Bahama Islands.

Another *Aristolochia* swallowtail (*Papilio areas mylotes*, pl. 14, figs. 86–88) has been said to occur in the Gulf States, but the record is very dubious. Its home is in Central America.

THE FLUTED SWALLOWTAILS

The second and largest section of the genus *Papilio* includes the so-called fluted swallowtails. These are especially characterized by having the inner margin of the hind wings, next to the body, always curved abruptly downward so that it appears to be longitudinally grooved or fluted, particularly when viewed from the under side. In this feature both sexes are alike.

The caterpillars of the fluted swallowtails are more varied than are those of the other groups. They are generally brightly colored, often streaked with patches of oddly mingled colors or provided with a few large eye-spots, giving them a startlingly grotesque appearance.

In contrast to the *Aristolochia* swallowtails, the antennae of the fluted swallowtails are scaled at the base and are distinctly jointed, the segments being more or less narrowed basally and somewhat compressed. The bodies of the fluted swallowtails are hard and brittle, and even a slight pinch on the thorax will kill, or at least permanently disable, them.

In habits the fluted swallowtails are more varied than the species of either of the other sections of *Papilio*. Most of them are noticeably shyer than the *Aristolochia* swallowtails. Some, especially among the larger kinds, sweep and sail along with occasional heavy flapping of the wings in clearings or about the borders of woods, or even over the tree tops; others fly about in a rather leisurely but very matter-of-fact way, as if they knew exactly what they wanted and were going after it; many have a swift and direct nervous fluttering flight and keep their wings constantly in motion when on flowers; while a few have an awkward, clumsy flight of such a stupid nature as to appear wholly foreign to any swallowtail. Some of the species keep mostly in or very near the woods, others live equally in woods and in more or less open bushy country or in orchards, and a few are confined to open country. They

vary greatly in abundance. Some are very common, others are frequent, but never common, and a few are always rare.

The caterpillars feed on a very great variety of different plants, though mostly on shrubs or trees; only a few feed on herbaceous plants. The orange family (Rutaceae) is especially the favorite, and in every region where oranges are grown one or more kinds of fluted swallowtails are more or less a pest upon them. More or less strongly aromatic plants belonging to the laurel, magnolia, carrot, and aster families (Lauraceae, Magnoliaceae, Apiaceae, and Asteraceae) are also favored, and a few species are more or less of a pest upon parsley, parsnips, celery, and related plants (Apiaceae). But, besides these aromatic plants, very many other kinds in a great number of different families are also fed upon by the caterpillars of the fluted swallowtails.

Many species feed only on a single kind of plant, some will feed on several closely related or chemically similar plants, and a few are general feeders. One of the most remarkable is our yellow swallowtail (*Papilio glaucus*), which is equally at home on a great variety of plants belonging to more than a dozen different families.

Fluted swallowtails are cosmopolitan, and range much farther to the northward than the species of the other sections. In Europe one and in North America two cross the Arctic Circle. But the great majority are tropical.

Though none are so large as the giant *Aristolochia* swallowtails of New Guinea and adjacent islands, some of the fluted swallowtails are of imposing size. The largest of all (*Papilio antimachus*), from 9 to 12 inches in maximum expanse, is found in tropical west Africa. This is a curious-looking butterfly, with the fore wings very long and narrow. The female, which is very rare, is much smaller than the male, just under 6 inches in expanse. The largest swallowtail in America, *Papilio homerus* of Jamaica, nearly 7 inches in expanse and with very broad wings, is a member of this section. But this section also includes some of the smallest species of *Papilio*.

A number of fluted swallowtails are more or less perfect imitations of various other kinds of butterflies. Some are imitations of *Aristolochia* swallowtails, others of milkweed butterflies or their allies, or of heliconians. This imitation may be confined to the females, or it may include both sexes.

OUR NATIVE FLUTED SWALLOWTAILS

Nature has treated us exceptionally well in the matter of fluted swallowtails, for no less than 18 different kinds occur within our borders—if we include Alaska. And some of these are unusually interesting.

From Europe and northern Africa eastward through Asia north of the Himalayas to Kamchatka and Japan there lives a yellow swallowtail (*Papilio machaon*) that is also found in Alaska, Yukon, and Mackenzie (var. *aliaska*, pl. 13, figs. 73, 74), and from Hudson Bay to Lake Superior (var. *hudsonianus*, pl. 13, figs. 71, 72). In the northwest the butterflies resemble most closely others from western China and the Himalayas; in the northeast they differ but slightly from European individuals. This is the only Old World swallowtail found in America. It ranges farther north than any other Old World swallowtail, in Europe passing the Arctic Circle. Also in Alaska it passes the Arctic Circle, but here it is accompanied by our common yellow swallowtail (*Papilio glaucus*, pl. 8, fig. 30).

Very similar to the European yellow swallowtail is another with more black upon the body and a round black pupil in the orange spot on the hind wing (*Papilio zelicaon*, pl. 13, fig. 75) that ranges from British Columbia to Lower California.

Also very similar is still another, or rather one color type of another; for this particular butterfly (*Papilio bairdi*, pl. 12, figs. 55–57; pl. 13, figs. 67–70) has two entirely different styles of coloration. It may be yellow with dark markings (pl. 13, figs. 67–70), resembling the European swallowtail but with a black pupil in the orange spot on the hind wing, or it may be black with a yellow band across the wings (pl. 12, figs. 55–57), closely resembling our common eastern parsnip swallowtail (pl. 12, fig. 59). Five different varieties are recognized, three of the yellow-color type and two of the black. Each variety has its own special range. In some places black and yellow individuals occur in about equal numbers, in others the yellow outnumber the black about 50 to 1, and in still others, in the south, no yellow ones are found.

In Alberta, Saskatchewan, and Montana there lives a rare black swallowtail (*Papilio nitra*, pl. 12, fig. 58) that is probably only an additional form of the preceding.

The common black eastern parsnip swallowtail (*Papilio polyxenes*, pl. 12, figs. 59–61; pl. 13, figs. 76, 77) ranges from Newfoundland and Hudson Bay to Wyoming, and southward to Peru and Venezuela. Throughout its range in the United States it is generally common—in many places the commonest of the swallowtails. In the extreme northeast the sexes are alike, but over most of the range they differ. Our common form (*asterius*) in Central America has three very different looking styles of males, two, or in some places all three, flying about together; but the females resemble those that flit about over our clover fields in the Eastern States, and one of the three males is like our native males. All three types of males occur in our Southwestern States, from which, besides, two other forms

of the butterfly (*americus*, pl. 13, figs. 76, 77, and *stabilis*) have been recorded. The United States National Museum possesses specimens of the first from Arizona and from Texas, and of the second from Texas.

In California and adjacent States, chiefly at high altitudes, there lives a rather scarce black swallowtail (*Papilio indra*, pl. 12, figs. 63, 64), more or less resembling the preceding. It is divided into a northern (*indra*, pl. 12, fig. 63) and a southern (*pergamus*, pl. 12, fig. 64) race.

Largest of all the butterflies found in the United States is a magnificent yellow and brown swallowtail (*Papilio thoas*, pl. 9, figs. 34, 35; pl. 10, figs. 42, 43), common in tropical America but more or less of a visitor with us. One form of this with the yellow very pale (*autocles*, pl. 9, fig. 35; pl. 10, fig. 43) is known from Texas and from the Everglades in Florida. A second (*nealces*, pl. 10, fig. 34; pl. 10, fig. 42), much deeper yellow, occurs in Arizona.

Much like this is the giant swallowtail (*Papilio cresphontes*, pl. 9, fig. 37) of the eastern States, very common in the South, a handsome, stately butterfly that glides easily along with occasional flaps of its large wings, and when feeding keeps its wings widely spread as if to give the entomologist a treat and at the same time convey a challenge. The caterpillars of this butterfly—known as "orange-dogs" or "orange-puppies"—often do more or less damage to young orange trees.

Very similar is another kind (*Papilio ornythion*, pl. 9, fig. 36; pl. 10, fig. 44), without any yellow on the tails above, that is found in Texas and is more common farther southward.

Known only from the vicinity of Miami, Fla., where it is rare, is a local race (*ponceana*, pl. 9, figs. 38, 39) of another species of the same general type (*Papilio aristodemus*) found elsewhere on Cuba and on Haiti. This species has also been recorded from Key West, but whether the specimen from Key West represents the Florida (*ponceana*) or the Cuban (*temenes*) form has not been determined.

Another quite different butterfly of the same group (*Papilio andraemon bonhotei*) occurring in the Bahamas has also been recorded from Miami.

The common eastern yellow swallowtail (*Papilio glaucus*, pl. 8, figs. 30, 31; pl. 9, fig. 40; pl. 10, fig. 41; pl. 12, fig. 65) is well known to everyone in the regions where it lives. Ranging from central Alaska to Hudson Bay and southward to Florida and Texas, it is, in most places, a common butterfly. In the eastern mountains and northward and northwestward it is abundant, usually far outnumbering the other local swallowtails. Male yellow swallowtails are always yellow. In the southernmost portion of the range the females usually are blackish brown, rarely or occasionally yellow.

Farther north yellow females become more common, and in the northern portion of the range the females are all yellow. The yellow females are very variable. They usually differ more or less widely from the males, but in some localities are exactly like them, or a greater or lesser proportion of the females will be like the males. Intermediates between the black and yellow females are rare. The caterpillars of the yellow swallowtail are commonly known as "elephant-worms." They feed on a great variety of different plants. In the north they are commonly found on apple, pear, and cherry, and especially wild cherry. They are seldom common enough to do appreciable damage.

In the western States this familiar swallowtail is represented by a closely allied kind (*Papilio rutulus*, pl. 8, fig. 32) that is much the same in habits. In this both sexes are alike.

Similar to the two preceding, but white instead of yellow, is another common and wide-ranging western swallowtail (*Papilio eurymedon*, pl. 8, fig. 33).

In the drier regions of the west from British Columbia to Guatemala lives a related sort (*Papilio multicaudata*, pl. 8, fig. 28; pl. 10, fig. 45) easily distinguished from the others by the possession of two conspicuous tails on each hind wing.

The occurrence of three tails on each hind wing distinguishes our last swallowtail of this general type, a rather uncommon species (*Papilio pilumnus*, pl. 8, fig. 29; pl. 10, fig. 46) found from the southwestern border States southward to Guatemala.

Moist open woods and nearby fields and gardens form the favorite habitat of the spice-bush swallowtail (*Papilio troilus*, pl. 11, figs. 49, 50) of the eastern States, which in certain regions is the commonest of all the swallowtails. The caterpillars in the South are known as "mellow-bugs." They feed chiefly on spice-bush and on sassafras, and are sometimes locally abundant.

Characteristic of the great swamps of the southeastern States is the large and handsome magnolia swallowtail (*Papilio palamedes*, pl. 11, figs. 47, 48). In those regions that are especially suited to it, as for instance the Great Dismal in eastern Virginia, it is very common—indeed, the most numerous of the swallowtails. It is rather a prosaic insect, flapping its steady way among the trees with a somewhat heavy flight, seemingly with some purposeful idea of getting somewhere. The caterpillars live on magnolia trees.

The only tailless fluted swallowtail recorded from the United States (*Papilio anchisiades idaeus*, pl. 14, figs. 84, 85) is a dark dingy brown with a large red spot on the hind wings. It is said to have been captured at or near Marfa, Tex. In tropical America this butterfly, in various forms, is very common and its caterpillars frequently are a serious pest on orange trees.

THE KITE SWALLOWTAILS

The most characteristic species of this section, such as our zebra swallowtail (*Papilio marcellus*, pl. 13, fig. 78; pl. 14, fig. 89), the "scarce swallowtail" of England (*P. podalirius*), and the silky white swallowtails of South America (*P. protesilaus*, etc.), are white and have the wings shaped somewhat like a paper kite.

The caterpillars, like those of the fluted swallowtails, have the third segment behind the head enlarged, the body tapering very gradually toward the tail and more abruptly toward the head. There are no eye spots or oblique bands, the pattern consisting of small dots or several transverse lines on each segment.

In the butterflies the antennae have a more distinct club than in the two other sections, and the upper side of the antennae is scaled, though in most species the scales readily fall off.

The abdominal margin of the hind wings is broadened in the males, and usually bears a distinct scent organ. The scaling of the wings is often less dense than in the fluted swallowtails, the wings in many species becoming transparent outwardly. The bodies of the kite swallowtails are rigid and brittle, and most of them are easily killed by a slight pinch.

The kite swallowtails are cosmopolitan, but they do not range so far north or south as the fluted swallowtails, and they are not so numerous in species as the other two sections. They also vary less in size, and the upper and lower surfaces of their wings differ less in color. The largest (*Papilio payeni evan*) is not over 5½ inches in expanse, and some scarcely exceed 2½ inches. Most of them are between 3 and 4 inches in expanse. The American kite swallowtails show a greater variety in structure, shape, and pattern than the Old World species. Some of the species, like some of the species of fluted swallowtails, are mimics of other butterflies.

In their habits the kite swallowtails show less diversity than do the swallowtails of other groups. They are nervous, quick, and rather shy, with a rapid direct flight which usually is rather low. They live chiefly in rugged open country, or in partly wooded regions, but a few are forest dwellers. They are especially common in the scattered brush on the edges of forests and on land once cultivated but abandoned and grown up to brush.

The caterpillars for the most part feed on plants of the custard-apple family (Anonaceae).

OUR NATIVE KITE SWALLOWTAILS

In the eastern portion of the United States the black and white striped zebra swallowtail (*Papilio marcellus*, pl. 13, figs. 78; pl. 14, fig. 89) is locally quite common. The individuals seen in early

spring (pl. 14, fig. 89) are very small and very hairy, with a minimum of black. They keep mostly to the woods and have a fluttering nervous flight. Their children, appearing in the summer (pl. 13, fig. 78), are much larger with more black and shorter hair on the head and body. They are likewise less energetic, with a less hurried and more sailing flight, and wander more widely over open country. In late spring or early summer a form intermediate between these two is found. The caterpillars feed on the pawpaw (*Asimina triloba*) and its relatives, living fully exposed upon the leaves of the food plant. They are solitary, though often numerous, and are especially prone to cannibalism.

Much like the smallest individuals of the zebra swallowtail is a smaller kind (*Papilio celadon*, pl. 14, figs. 90, 91) living in Cuba that occasionally is found in southern Florida.

THE LESS FAMILIAR SWALLOWTAILS

Though the great majority of the butterflies belonging to the group of swallowtails—that is, to the family Papilionidae—are included in one or other of the three sections of the large genus *Papilio*, a number of different kinds vary more or less widely from these typical swallowtails.

These relatives of the typical swallowtails are distributed in 12 different genera, mostly very small—in fact, 7 of them have only a single species each, and 2 have only 2. Of these 12 genera one, much the largest, lives in the mountains of Europe, Asia, and western North America, where the species form a conspicuous and attractive element in the alpine scenery. Another is found only in the highlands of western Mexico. One lives only in southern South America. A fourth lives in New Guinea and in north Australia, a fifth lives in southern Europe and in western Asia, and the rest are confined to Asia, one of them extending into the larger Malayan islands.

THE DRAGONFLY SWALLOWTAILS

From northern India and southeastern China to Java, Celebes, and the Philippines this last is found. It is a genus of curious dwarf swallowtails (*Leptocircus*; pl. 1, fig. 2) which, though essentially diminutive kite swallowtails, are more or less like skippers in appearance. There are two kinds of these, each divided into several different races. They have transparent, black-lined wings showing a stripe of white or greenish white, and the silver-edged tails of the hind wings are very long. An example of *Leptocircus meges* which I have before me measures 1¾ inches in maximum expanse, and the hind wings with the tails have a length of 1⅞ inches.

In most places in the regions they inhabit these little butterflies are very common. They are found in the vicinity of water, settling

on the edges of the streams or flying back and forth in the sunshine over the pools and brooks with the same hurrying direct flight as the kite swallowtails. But on first acquaintance they look as they flit about more like dragonflies than butterflies.

SOME OTHER STRANGE SWALLOWTAILS

In northern Australia and New Guinea there lives a butterfly (*Eurycus cressida*, pl. 4, fig. 9) which, except that it is brownish instead of white in color, suggests a parnassian. It is very common in suitable localities and sometimes swarms about the flowers of the *Eucalyptus*. It is curious in having the female smaller than the male. The flight is direct and rather feeble. The caterpillars feed on *Aristolochia*.

Somewhat similar are two other butterflies, one with tails and one without, belonging to the genus *Euryades*. These live along the Rio Paraná and its tributaries in Paraguay and Argentina in southern South America.

STILL STRANGER SWALLOWTAILS

From Nepal to Tenasserim and northward to central China there lives a curious stout-bodied butterfly (*Teinopalpus imperialis*, pl. 2, figs. 3, 4) that is very widely different from all other swallowtails. The male has one and the female two long tails on each hind wing. The males have a very swift flight and usually keep high above the ground, flying about high trees, in their actions as well as in their form resembling large and powerful nymphalids much more than they do swallowtails. The females are seldom caught. This butterfly is very local and there are several local races. It lives in mountain forests usually at an altitude of between 6,000 and 10,000 feet.

Very curious butterflies are the two species of *Armandia*, one, a large and handsome insect (*Armandia lidderdalei*, pl. 5, fig. 14), living in northwestern Burma and Bhutan and thence to western China, the other (*Armandia thaidina*), smaller, occurring in Szechuan. The smaller species (*A. thaidina*) has three tails, one very long and spatulate, and two shorter ones between this and the anal angle. The larger (*A. lidderdalei*, pl. 5, fig. 14) has still another tail just in front of the longest one. These butterflies fly in summer, sailing about with a slow and undulating flight like that of the "ghost butterflies" (*Hestia*) high up among the tree tops, often permitting themselves to be carried by the wind, so that they appear more like falling leaves than they do like butterflies.

From Amurland southward to Japan and westward to central China live the three forms of the single species of the curious genus *Luehdorfia* (pl. 7, figs. 24, 25). These are medium-sized butterflies

with a single short tail on each hind wing, short antennae, and a densely hairy body. They fly in early spring, sometimes while there is still snow on the mountain sides. Their flight is slow and weak. They are usually common wherever they occur.

From Vladivostock to beyond Shanghai and westward to Szechuan, common everywhere in the Yangtse Valley, there lives a very pretty butterfly (*Sericinus telamon*, pl. 3, fig. 8). This occurs in about 10 local races, in each of which the spring and summer broods differ from each other. All the forms of this butterfly are very local, but they are usually abundant wherever they are found. They have a slow, uncertain flight and are fond of flowers. They appear in spring, and again as a larger form with longer tails in the middle of the summer.

Very closely allied to the species of *Sericinus* are the four species of the genus *Thais* (pl. 4, figs. 10, 11), which live from the Mediterranean countries eastward to Iran. These are rather smaller butterflies than the preceding, with stouter bodies and scalloped, but not tailed, hind wings.

These butterflies have only one brood, which appears in early spring. They frequent sunny slopes, especially rocky hills, vineyards, and the borders of woodlands, and are locally common. In some places in Asia Minor they appear in enormous numbers. They are fond of flowers, and especially of yellow composites. Abnormally colored individuals are common, and some of these color aberrations are very local.

Resembling medium-sized and highly colored parnassians are the very varied local forms of *Archon apollonius* (pl. 7, figs. 26, 27), which in some ways is intermediate between the species of *Thais* and the species of *Parnassius*. This butterfly is found from Asia Minor to the Caucasus and Iran, flying in early spring. Its flight is slow and hesitating. Like all its relatives, it is fond of flowers.

In its size, in the shape of its wings, and in its color appearing much more like a pierid than like a swallowtail, though suggesting certain species of *Parnassius*, is the curious *Hypermnestra helios* (pl. 3, figs. 6, 7), which in several different forms is found in Turkestan and northern Iran. It is found in early spring on steep and sunny slopes, and in suitable localities it is rather common. The flight is slow and vacillating, and the insects often pause to feed on flowers.

THE PARNASSIANS

Next to *Papilio*, the largest and most important of the genera included in the family of swallowtails, or Papilionidae, is *Parnassius* (pl. 4, figs. 12, 13; pl. 5, figs. 15, 16), including the parnassians proper. The species of *Parnassius* number slightly over 40. Nearly

all of them are very variable locally and individually, so that many hundreds of local races and varieties already have been named.

Except in the British Isles, parnassians are found everywhere in Europe in the mountain regions, living from moderate altitudes up to the highest limit of possible existence. Eastward they are found everywhere in Asia southward to the cold high altitudes of the Himalayas in northern Indian, and, passing over to Alaska, they occur in the mountain region of western North America southward to New Mexico, where 4 species and about 50 forms are recognized.

Preeminently alpine butterflies are the parnassians, preferring the colder regions of the higher altitudes. In Asia they live up to more than 20,000 feet, or more than 3¾ miles, above the sea. They occur in the greatest variety and abundance in the Himalaya Mountains and thence northward to the mountains of Turkestan, Tibet, and western China. Here are found the largest and the smallest. The most beautiful are from the mountains of northern India, where alone these insects have two broods a year. Although parnassians live in the very coldest portion of the world, in central eastern Siberia, none of them are found so far north as the Arctic Circle, although some approach it rather closely in Europe, in Asia, and in Alaska. Our common and familiar yellow swallowtail (*Papilio glaucus*, pl. 8, fig. 30) in central Alaska ranges much farther north than any of the parnassians, passing well beyond the Arctic Circle, and the yellow swallowtail of Europe, north Africa, Asia, and northern North America (*Papilio machaon*, pl. 13, figs. 71, 74) also passes the Arctic Circle in Europe and in Alaska.

All parnassians are very similar in the shape and structure of their wings. All are of medium size or rather large. The largest are nearly 4 inches in expanse, the smallest about 2 inches. Most of them expand between 2½ and 3 inches.

In the bleak and desolate alpine regions, which they especially prefer, their large size and conspicuous white color make the parnassians the most noticeable of all the forms of animal life except, perhaps, for certain birds and an occasional alpine mammal. Even the most casual observer cannot fail to see them and to wonder how such frail creatures can exist among such harsh surroundings.

In the strong sunshine of the late morning or the early afternoon parnassians are very active flying back and forth across the alpine meadows with a fairly rapid uncertain fluttering flight.

They rarely rise more than a foot or two above the ground. They are never shy and are very easily caught either by intercepting them in their flight or by picking them off flowers on which they feed with more or less widely extended wings. As it grows colder in the afternoon their flight becomes more leisurely; becoming chilled, they are more and more reluctant to take wing. Toward evening they become

quite torpid and inert. Some of them have the habit of flying in long erratic zigzags up the mountain valleys in the morning sunshine, and gradually drifting down again in the afternoon.

Most of the parnassians are single brooded, but in some of the Indian species, as in *Parnassius hardwickii*, there are two broods that are divided into a lighter dry season form and a darker wet season form, and a winter form resembling the latter, all with numerous intergrades.

Some of the species of *Parnassius* pass the winter in the egg, others as caterpillars, still others in the chrysalis, and some as perfect butterflies.

In the State of Guerrero in western Mexico at about 4,500 feet above the sea lives the single species (*brevicornis*) of the curious genus *Baronia* (pl. 6, figs. 17–22; pl. 7, fig. 23), which is allied to the true parnassians, though superficially in the shape of its wings and in its color pattern it recalls, in a general way, some of the Asiatic milkweed butterflies. This insect has short antennae with a prominent club, and very short legs. It is usually yellow and black, the light areas on the under side of the hind wings having a lovely pearly luster. The females are very variable. They may be like the males, but with the yellow ground color more extended (pl. 7, fig. 23), or the yellow may be replaced by dull orange (pl. 6, figs. 19, 20), or they may be wholly dark brown or black (pl. 6, figs. 21, 22), except for a few small white spots in the apex of the fore wings.

CATCHING SWALLOWTAILS

In a popular Italian card game, "Il matto", or the crazy man, is depicted prancing about waving a net at a butterfly about the size of a large hawk. This is a fairly correct portrayal of the way swallowtails are popularly supposed to be collected and of the popular appraisal of the collector.

Collectors are of two sorts. There are those who wander about netting anything that may come their way in the hope of gathering up something of interest—after the fashion of Il matto. We can forget these. But there are others who know exactly what they want and just how to go about to get it.

If a collector happens to want swallowtails, he first learns what ones are found, or are supposed to be found, or are likely to occur, in the region to be visited at the time when he will be there. And he also learns all he can about the habits of each kind. Some of them will be found anywhere in open country, perhaps favoring the wetter or the drier regions; many will occur about the borders of the woods or in the woodland glades; a few will live wholly in the woods; and a very few will seclude themselves in bogs or swamps.

Most of our swallowtails are rather generally distributed, and in a favorable locality, at least in the eastern States, every local species will be found in greater or lesser numbers. But in the Tropics this is not the case—you must search the various kinds out in their own special haunts.

Sometimes it happens that of a certain kind you get only males. This often means that the females are to be found elsewhere, and a special search for them must be made. Of course, in many species females are far less common than the males—indeed, in quite a number no females ever have been captured.

Swallowtails have four main weaknesses that greatly aid in catching them. Practically all of them are extremely fond of flowers growing at a fair height above the ground. Some flowers are attractive to all, or nearly all, the swallowtails in a given region, as, for instance, the lilac, the butterfly bush, and the white lantana. Other flowers attract only certain kinds. Thus in the east the zebra swallowtail (*Papilio marcellus*) is the only one that will visit the flowers on low blueberry bushes; our other spring swallowtails will not descend to them. Also the giant swallowtail (*Papilio cresphontes*) seems to be the only one that appreciates the flowers of the trumpet vine.

When visiting a region, therefore, the first thing a collector does is to locate the most likely looking gardens, and the proper flowering shrubs along the forest edge and in the glades and clearings in the woods. Often it is necessary to cut a cleared space about the flowering shrubs in and near the woods to give both the swallowtails and the collector freer access to them. After a number of the proper sort of gardens and of wild flowering bushes have been located, they are visited in rotation until a good series of all the local kinds has been secured.

Many swallowtails, though by no means all, are extremely fond of sucking up water from the wet banks of streams, or from barnyard puddles. Our yellow swallowtail (*Papilio glaucus*), where it is abundant, sometimes congregates in hundreds on wet mud. All of those found on mud, at least with us, are males; the females prefer nectar. But well-patronized mud banks are most excellent places in which to secure good series of the males of many different species. Often after having been disturbed, the butterflies become wary and suspicious. Their confidence can be restored by cutting out imitation butterflies from paper of the proper color and placing these in appropriate positions as decoys on the mud.

Like the epicures of old, meat-eating swallowtails like their meat "high." Or, to put the matter in another way, many of the swallowtails are inordinately fond of the juices from decaying flesh.

Dead fishes or dead snakes especially are singularly attractive to them. Every collector soon learns just where and how to place this loathesome bait in forest paths and clearings to the best advantage.

Excrement is equally attractive to many different kinds.

With all these weaknesses swallowtails have one virtue. They may drink themselves stupid and helpless on the juices from a highly fragrant carcass, but alcohol, so very attractive to many other butterflies, scarcely appeals to them at all. I have yet to see an inebriated swallowtail. Neither will they enthusiastically follow up a trail of tobacco smoke, as do certain moths. Some kinds on a hot day hover hopefully about collectors, but what they are yearning for is his perspiration.

Rocky, exposed hilltops, especially in woods, and low, wet, open spots in woods and damp hollows in open fields always should be visited. Bare hilltops are often the playgrounds of the males of various kinds, and wet hollows are often the favorite haunts of females. Scrubby, rough country everywhere forms the chosen home of certain species.

Briefly, in order to be successful in the quest for swallowtails you must know all there is to know about your prospective victims and be able to outwit them.

EXPLANATION OF PLATES

(All the specimens figured are in the collection of the United States National Museum)

Plate 1

Figure 1. One of the largest swallowtails; *Papilio priamus urvilleanus*, female, from the Solomon Islands.

2. One of the smallest swallowtails; *Leptocircus curius walkeri*, from Mt. Lo-fou-shan, east of Canton, China; C. W. Howard.

Plate 2

Figure 3. *Teinopalpus imperialis*, male, from northern India.

4. Same, under side.

Plate 3

Figure 5. *Euryades duponchelii*, from Buenos Aires, Argentina.

6. *Hypermnestra helios.*

7. Same, under side.

8. *Sericinus telamon telamon*, from Seishin, Korea.

Plate 4

Figure 9. *Eurycus cressida*, male.

10. *Thais polyxena* var. *ochracea.*

11. Same, under side.

12. *Parnassius actius superbus*, Narym, Turkestan.

13. Same, under side.

PLATE 5

FIGURE 14. *Armandia lidderdalei.*
15. *Parnassius delphius* var. *nicevillei*, from Burzil Pass, Kashmir; cotype.
16. Same, under side.

PLATE 6

FIGURE 17. *Baronia brevicornis*, male, from Iguala, State of Guerrero, Mexico.
18. Same, under side.
19. *Baronia brevicornis*, female form *eusemna* (orange), from Sierra de Guerrero, Mexico; Roberto Muller; type, U. S. N. M. no. 14280.
20. Same, under side.
21. *Baronia brevicornis*, female form *phronima* (black), from Sierra de Guerrero, Mexico; Roberto Muller; type, N. S. N. M. no. 14281.
22. Same, under side.

PLATE 7

FIGURE 23. *Baronia brevicornis*, female, from Iguala, State of Guerrero, Mexico, 2,400 feet; June 1906.
24. *Luehdorfia puziloi japonica* var. *takamukuana*, from Tokyo, Japan. April 28, 1912.
25. Same, under side.
26. *Archon apollonius* var. *bellargus.*
27. Same, under side.

PLATE 8

(All figures one-half natural size)

FIGURE 28. *Papilio multicaudata*, male, from the Huachuca Mountains, Arizona.
29. *Papilio pilumnus.*
30. *Papilio glaucus*, female, from Essex, Mass., A. H. Clark, July 26, 1925.
31. *Papilio glaucus*, female, intermediate between the yellow and black forms, from Silver Spring, Md., A. H. Clark, August 3, 1927.
32. *Papilio rutulus*, from Shasta Retreat, Siskiyou County, Calif., June 24, 1930.
33. *Papilio eurymedon*, from Shasta Retreat, Siskiyou County, Calif., June 1917.

PLATE 9

(All figures one-half natural size)

FIGURE 34. *Papilio thoas nealces*, from Arizona; H. K. Morrison.
35. *Papilio thoas autocles*, from the Everglades, Florida, September 1900.
36. *Papilio ornythion*, male, from Saddle Mountain, Monterey, State of Nuevo Leon, Mexico; Roberto Muller.
37. *Papilio cresphontes*, male, from Kentucky.
38. *Papilio aristodemus ponceana*, from Miami, Fla.; type, U. S. N. M. no. 16774.
39. Same, under side.
40. *Papilio glaucus*, male, aberration *fletcheri*, from Bay of Islands, Newfoundland, July 24, 1907.

PLATE 10

(All figures one-half natural size)

FIGURE 41. *Papilio glaucus*, female, intermediate between the black and yellow forms, under side, from Washington, D. C.; William Schaus.
42. *Papilio thoas nealces*, under side, from Arizona; H. K. Morrison.
43. *Papilio thoas autocles*, under side, from the Everglades, Florida; September 1900.
44. *Papilio ornythion*, male, under side, from Saddle Mountain, Monterey, State of Nuevo Leon, Mexico; Roberto Muller.
45. *Papilio multicaudata*, under side, from the Huachuca Mountains, Arizona.
46. *Papilio pilumnus*, under side.

PLATE 11

(All figures one-half natural size)

FIGURE 47. *Papilio palamedes*, male, from Virginia Beach, Va.; William Schaus.
48. Same, under side.
49. *Papilio troilus*, male, Manassas, Va.; A. H. Clark, August 18, 1935.
50. *Papilio troilus ilioneus*, male, Miami, Fla.
51. *Papilio devilliers*, from Baracoa, Cuba.
52. Same, under side.
53. *Papilio philenor*, male, Cabin John, Md.; A. H. Clark, September 19, 1925.
54. *Papilio philenor*, female, under side, from Cabin John, Md.; A. H. Clark, September 19, 1925.

PLATE 12

(All figures one-half natural size)

FIGURE 55. *Papilio bairdi*, form *bairdi*, from Glenwood Springs, Colo.
56. *Papilio bairdi*, form *hollandi*, from Glenwood Springs, Colo.
57. Same, under side.
58. *Papilio nitra*, from Calgary, Alberta; June 19, 1898.
59. *Papilio polyxenes asterius*, male, from Silver Spring, Md.; A. H. Clark, July 24, 1927.
60. *Papilio polyxenes asterius*, male form *ampliata*, from Rincon, N. Mex.
61. *Papilio polyxenes asterius*, male aberration *calverleyi*, from New Lots, Queens County, Long Island, N. Y.; August 1863; type, U. S. N. M. no. 33963.
62. *Papilio polyxenes brevicauda*, from Beaver Pond, Spruce Brook, Newfoundland; June 21.
63. *Papilio indra indra*, from Colorado.
64. *Papilio indra pergamus*, from Cazadero, Calif.; March 31, 1898.
65. *Papilio glaucus*, black female, from Newfoundland; July.
66. *Papilio cresphontes*, aberration *maxwelli*.

PLATE 13

(All figures one-half natural size)

FIGURE 67. *Papilio bairdi*, form *brucei*, from Vineyard, Utah; August 24, 1931.
68. Same, under side.
69. *Papilio bairdi*, form *oregonia*, from British Columbia; June 12, 1898.
70. Same, under side.
71. *Papilio machaon hudsonianus*, female, from Kettle Rapids, Nelson River, Manitoba; July 8, 1914; type, U. S. N. M. no. 34478.
72. Same, under side.
73. *Papilio machaon aliaska*, from Alaska; June 29, 1921.
74. Same, under side.
75. *Papilio zelicaon.*
76. *Papilio polyxenes*, form *americus*, from Arizona.
77. Same, under side.
78. *Papilio marcellus*, summer form, from Cabin John, Md.; Hugh U. Clark, July 29, 1928.

PLATE 14

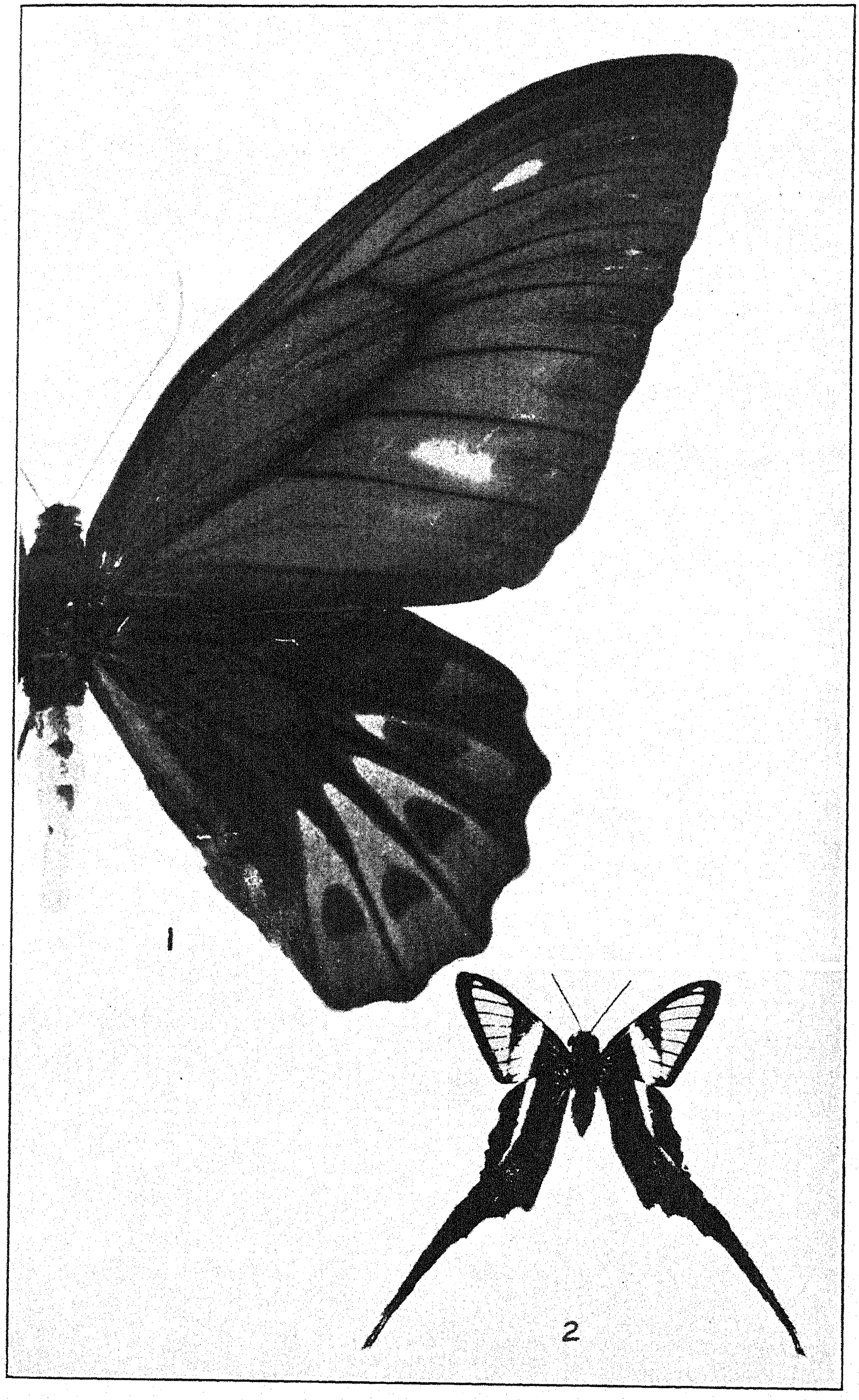
(All figures one-half natural size)

FIGURE 79. *Papilio polydamas polydamas*, from Texas.
80. Same, under side.
81. *Papilio polydamas lucayus*, from Bradentown, Fla.; December.
82. *Papilio philenor* var. *acauda*, from Washington, D. C.; A. H. Clark, May 7, 1932.
83. Same, under side.
84. *Papilio anchisiades idaeus*, from Honduras.
85. Same, under side.
86. *Papilio arcas mylotes*, male, Guapetes, Costa Rica; June.
87. Same, under side.
88. *Papilio arcas mylotes*, female, from the Zent District, Costa Rica; William Schaus, February 1907.
89. *Papilio marcellus*, female, early spring form, from Great Falls, Md.; A. H. Clark, May 2, 1926.
90. *Papilio celadon*, Chokoloskee, Fla.
91. Same, under side.

NOTES.—The specimen figured as *Papilio thoas nealces* and said to be from Arizona (pl. 9, fig. 34, and pl. 10, fig. 42) would appear to be the Brazilian *Papilio thoas brasiliensis.* There is no reason to suppose that the latter would occur in Arizona. There is probably some mistake in the labeling. Lord Rothschild and Dr. Karl Jordan have called attention to a similar error in the case of Dr. W. J. Holland's figure of the same species.

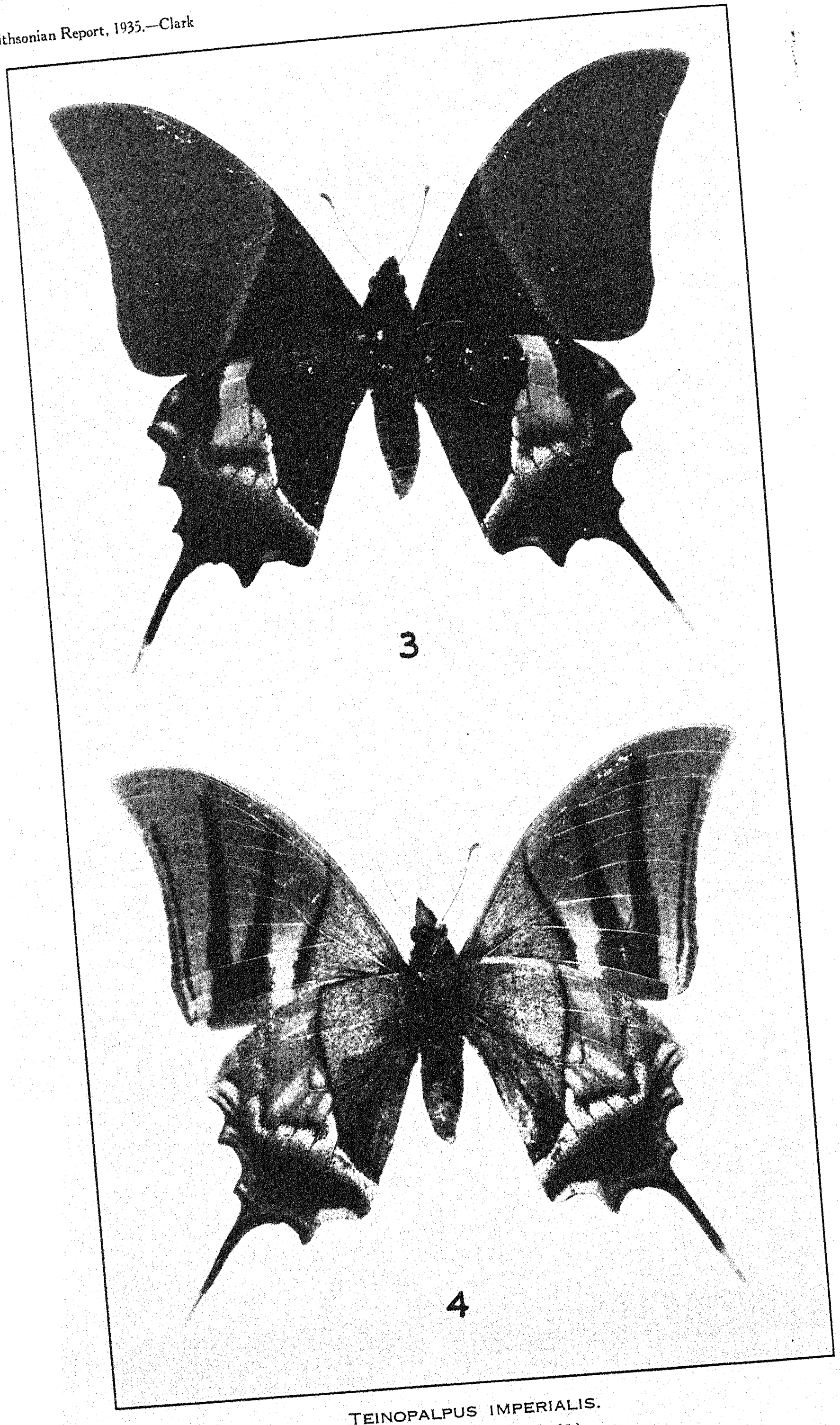
The black female of *Papilio glaucus* from Newfoundland (pl. 12, fig. 65) emphasizes the fact that in Newfoundland this species is represented both by the form *canadensis*, with both sexes alike, and by a dwarf variety of the southern form; between the two there are all possible intergrades.

The author is dubious regarding the origin of the specimen of *Papilio celadon* figured (pl. 14, figs. 90, 91); it probably came from Cuba.



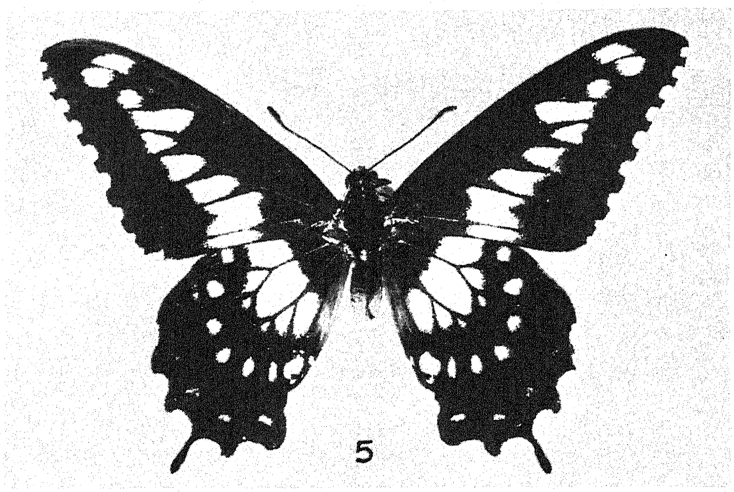
GIANT AND DWARF—A LARGE PAPILIO AND LEPTOCIRCUS.

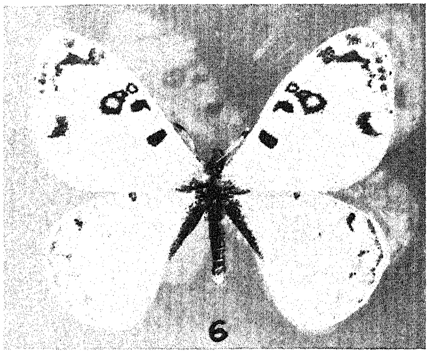
(For explanation, see p. 405.)

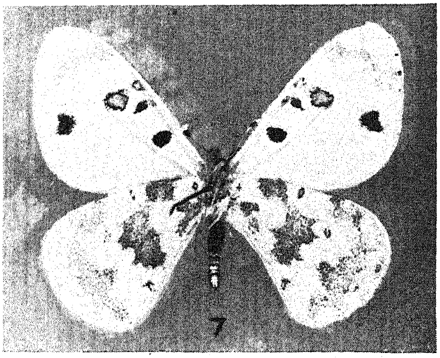


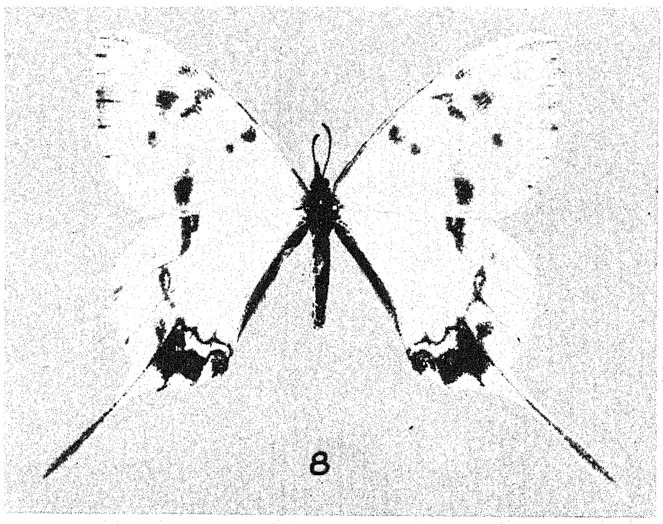
TEINOPALPUS IMPERIALIS.

(For explanation, see p. 405.)



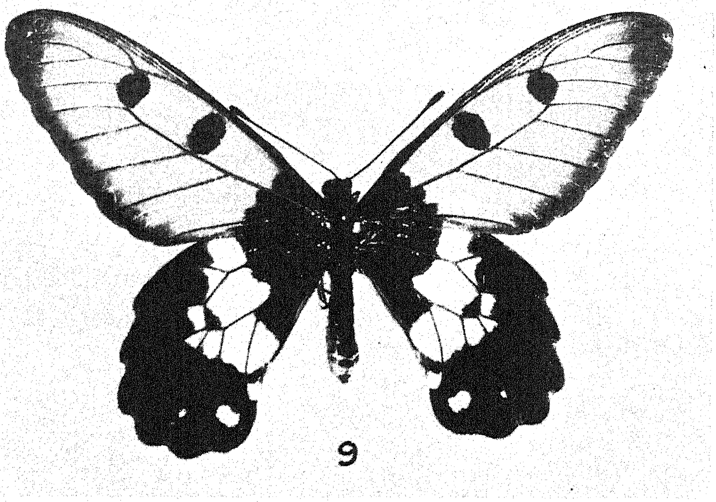


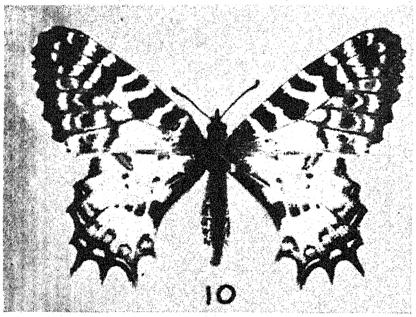


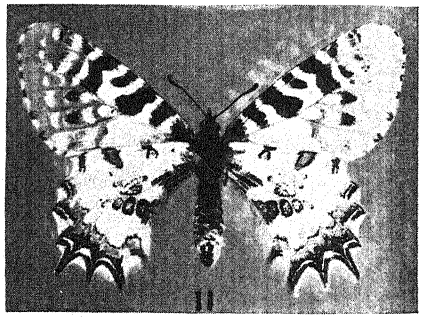


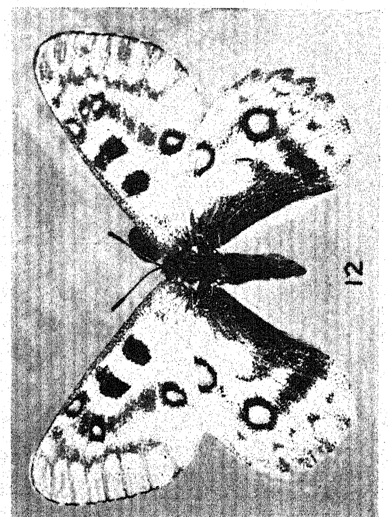
EURYADES, HYPERMNESTRA, AND SERICINUS.

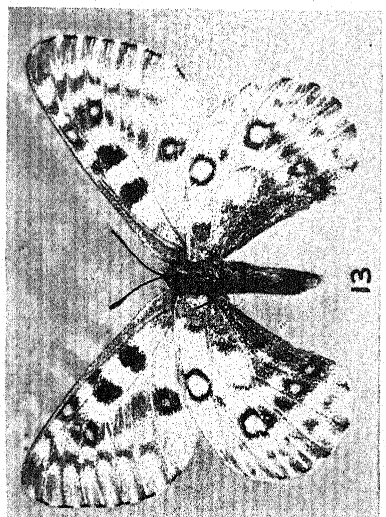
(For explanation, see p. 405.)





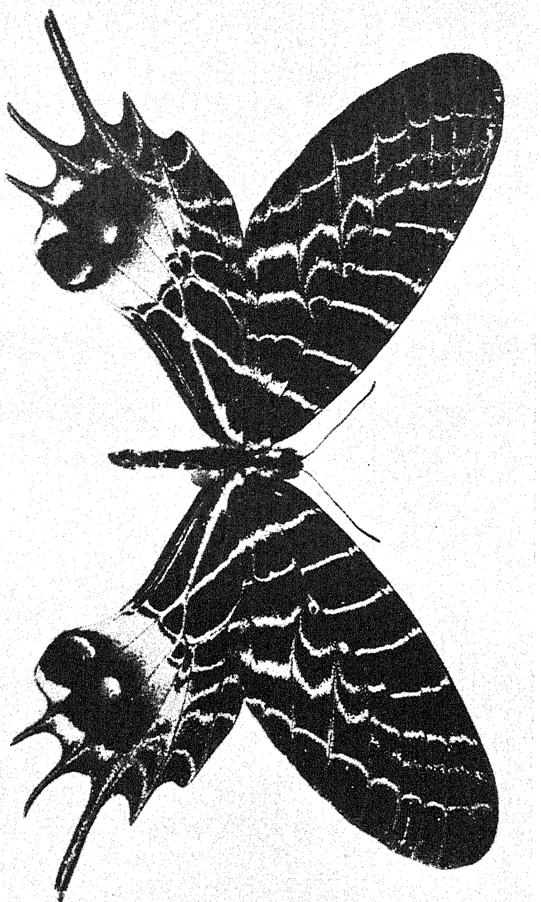






EURYCUS, THAIS, AND PARNASSIUS.

(For explanation, see p. 405.)



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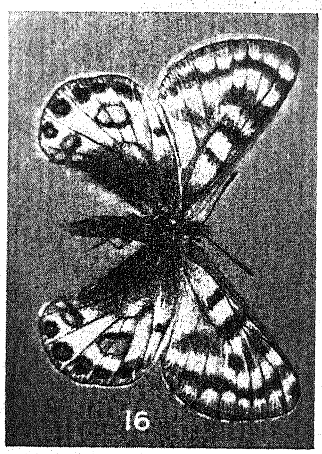
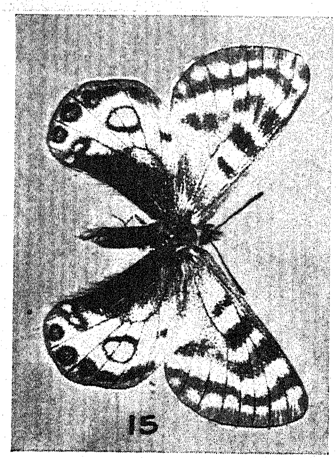
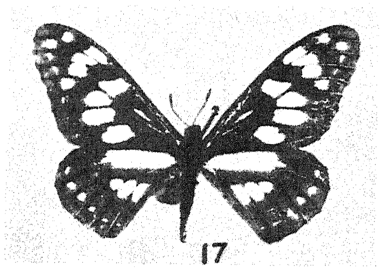
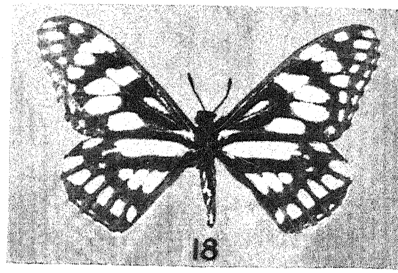


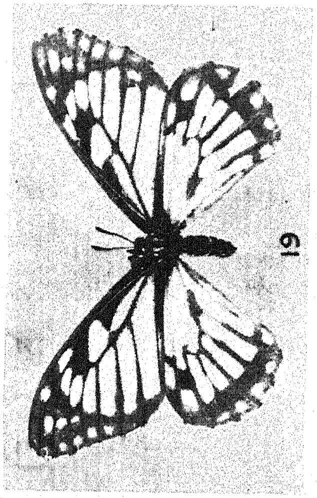


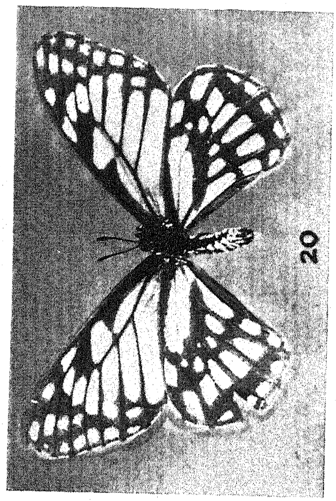
ARMANDIA AND PARNASSIUS.

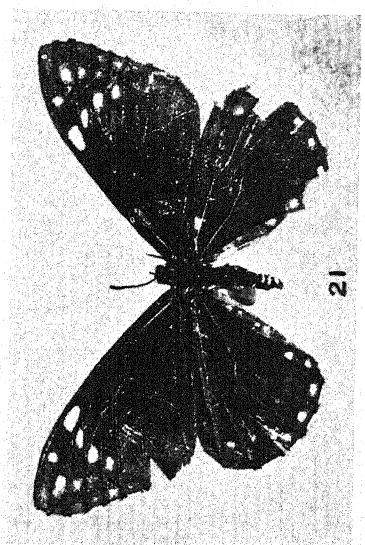
(For explanation, see p. 406.)

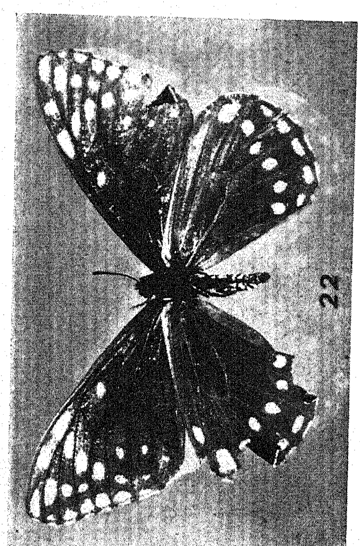






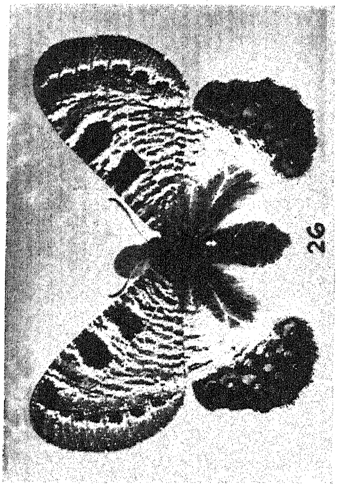


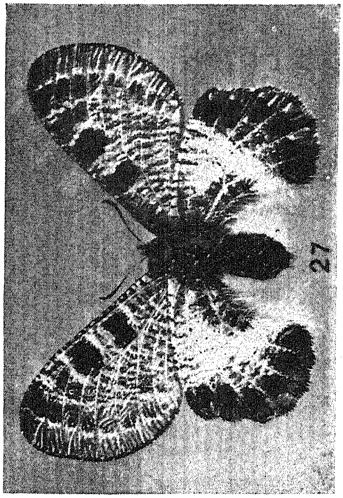


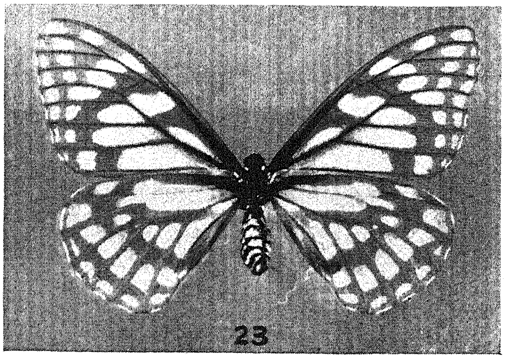


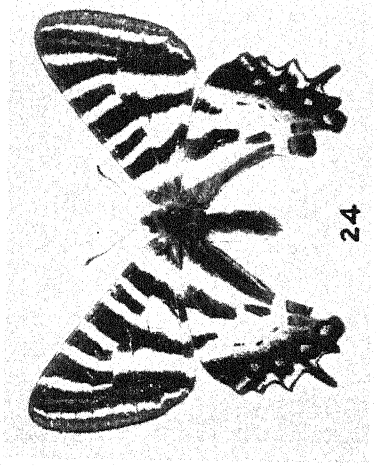
BARONIA BREVICORNIS.

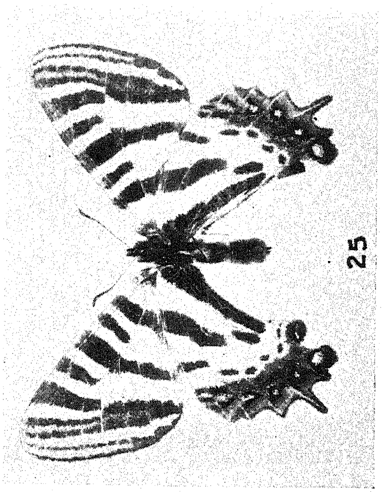
(For explanation, see p. 406.)





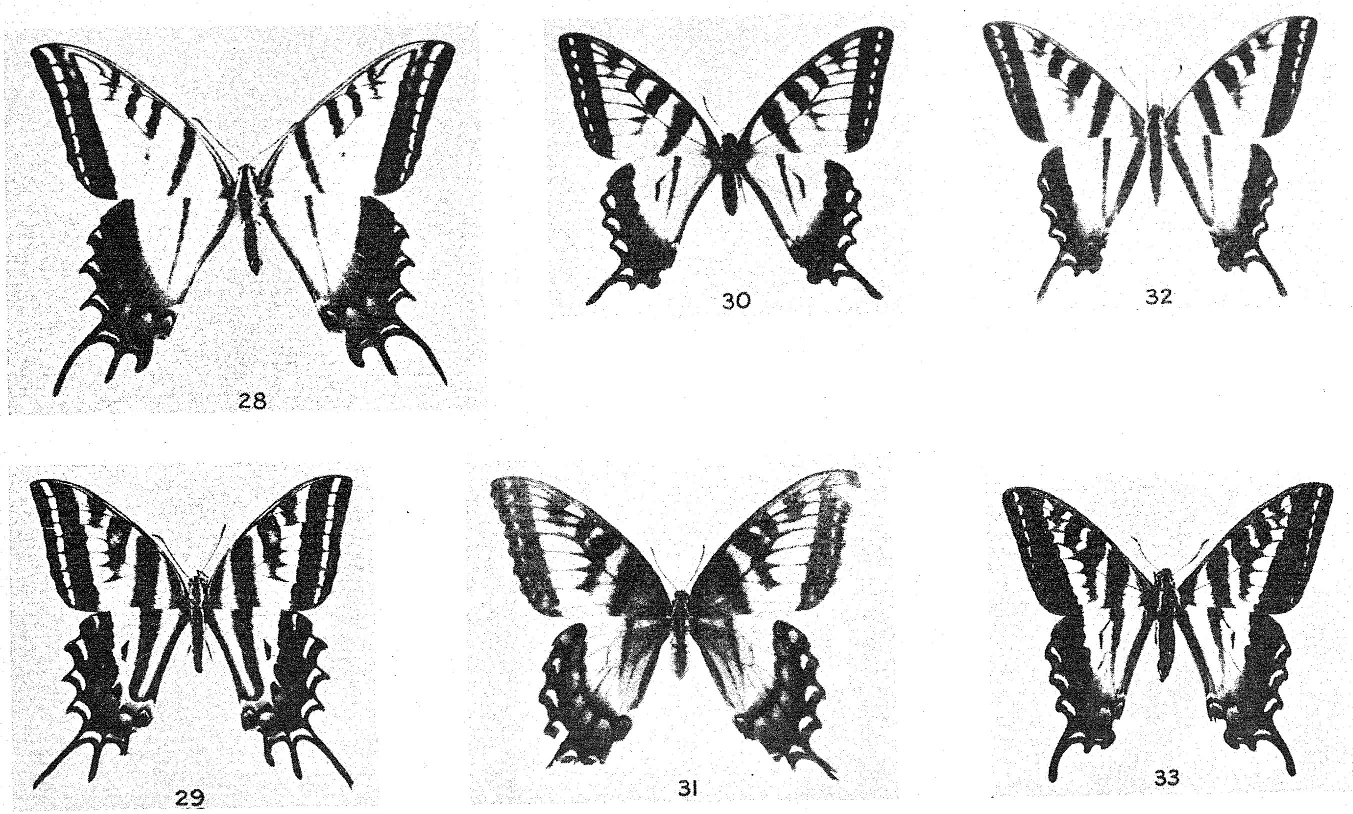






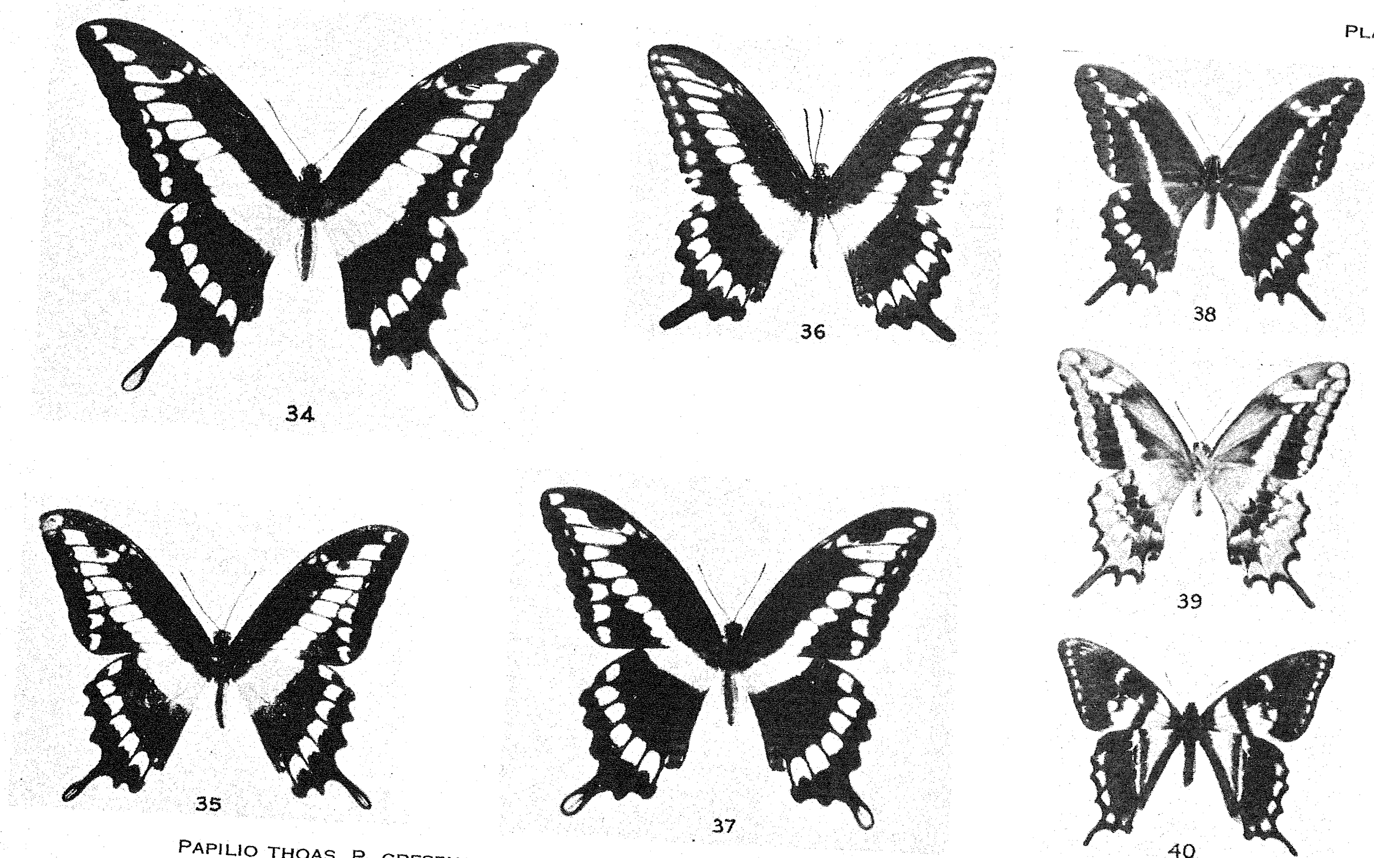
LUEDORFIA, BARONIA, AND ARCHON.

(For explanation, see p. 406.)



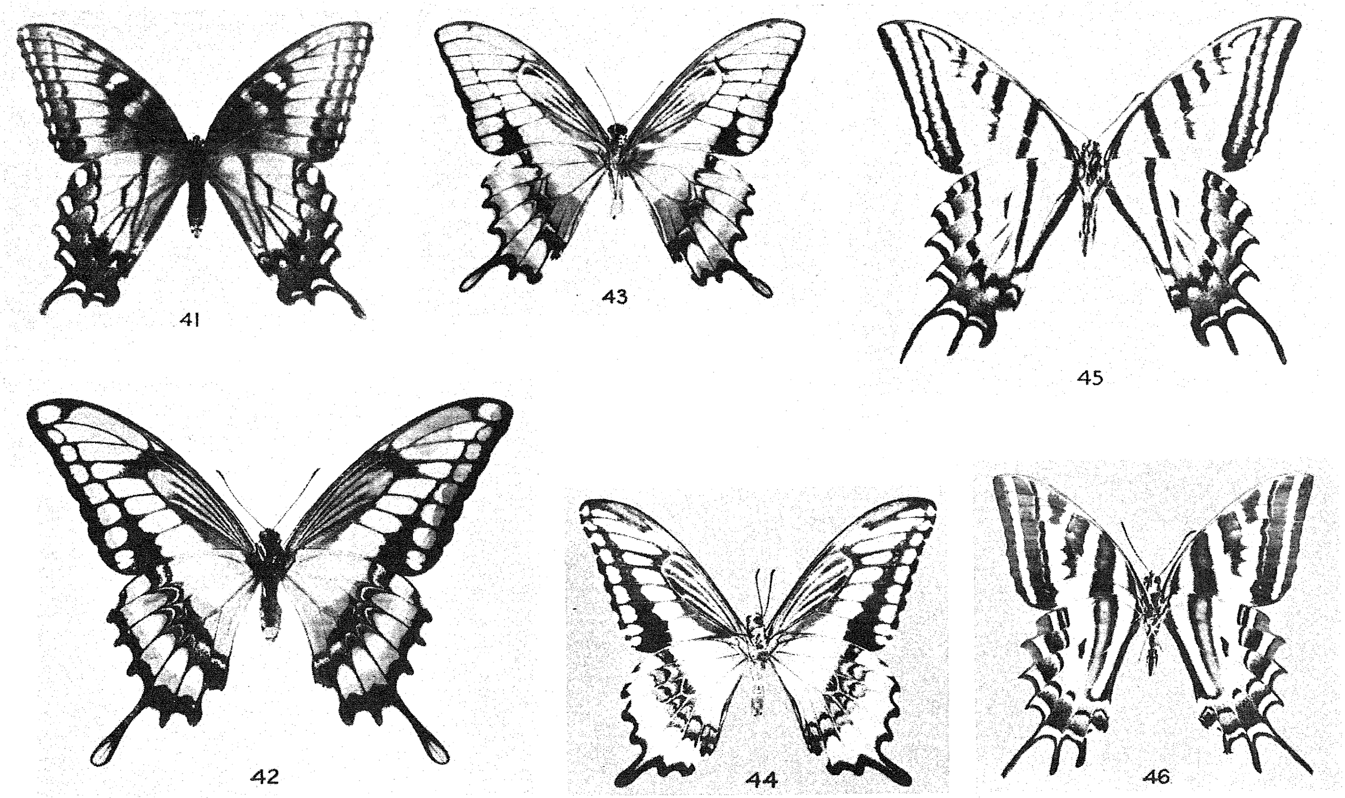
PAPILIO MULTICAUDATA, P. GLAUCUS, P. RUTULUS, P. PILUMNUS, AND P. EURYMEDON.

(For explanation, see p. 406.)



PAPILIO THOAS, P. CRESPHONTES, P. ORNYTHION, P. ARISTODEMUS, AND P. GLAUCUS.

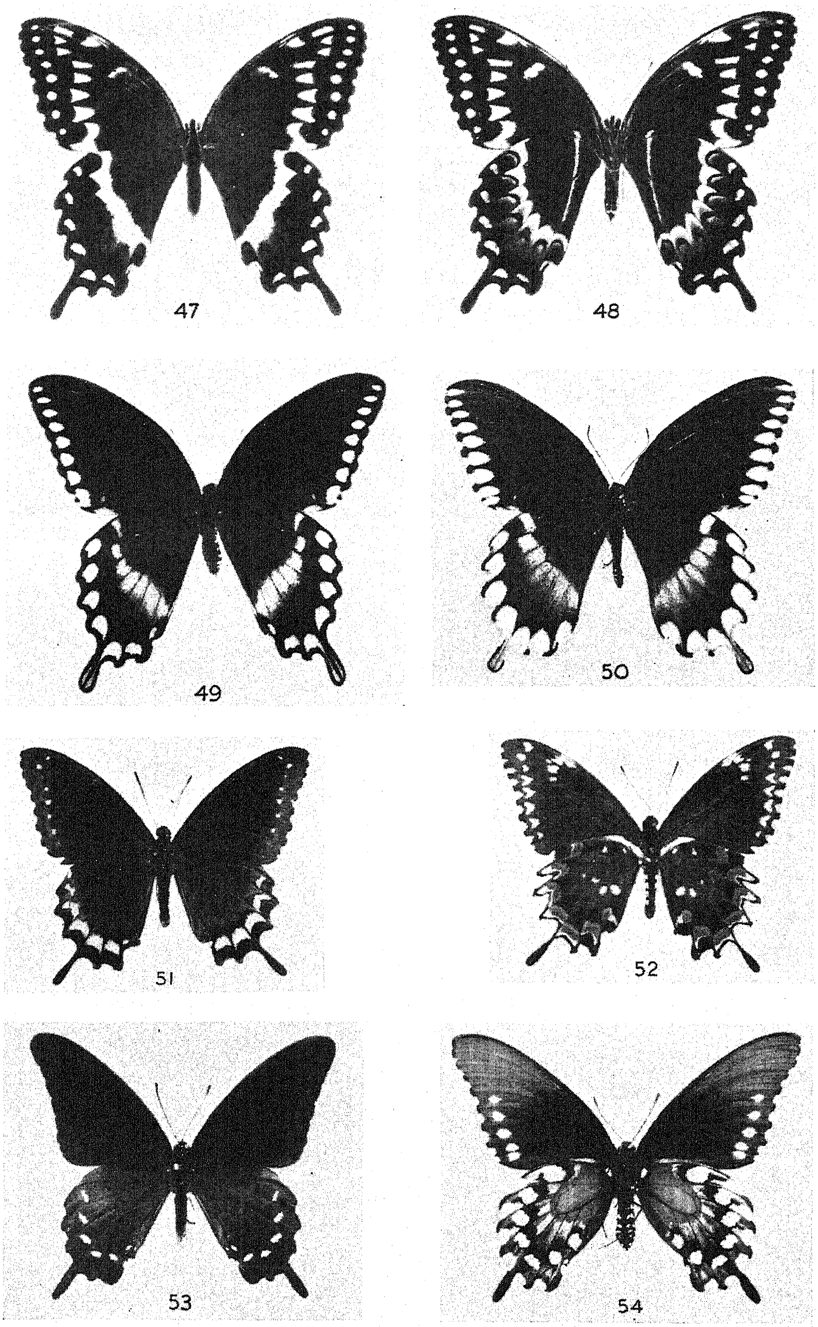
(For explanation, see p. 406.)



41 43 45 42 44 46

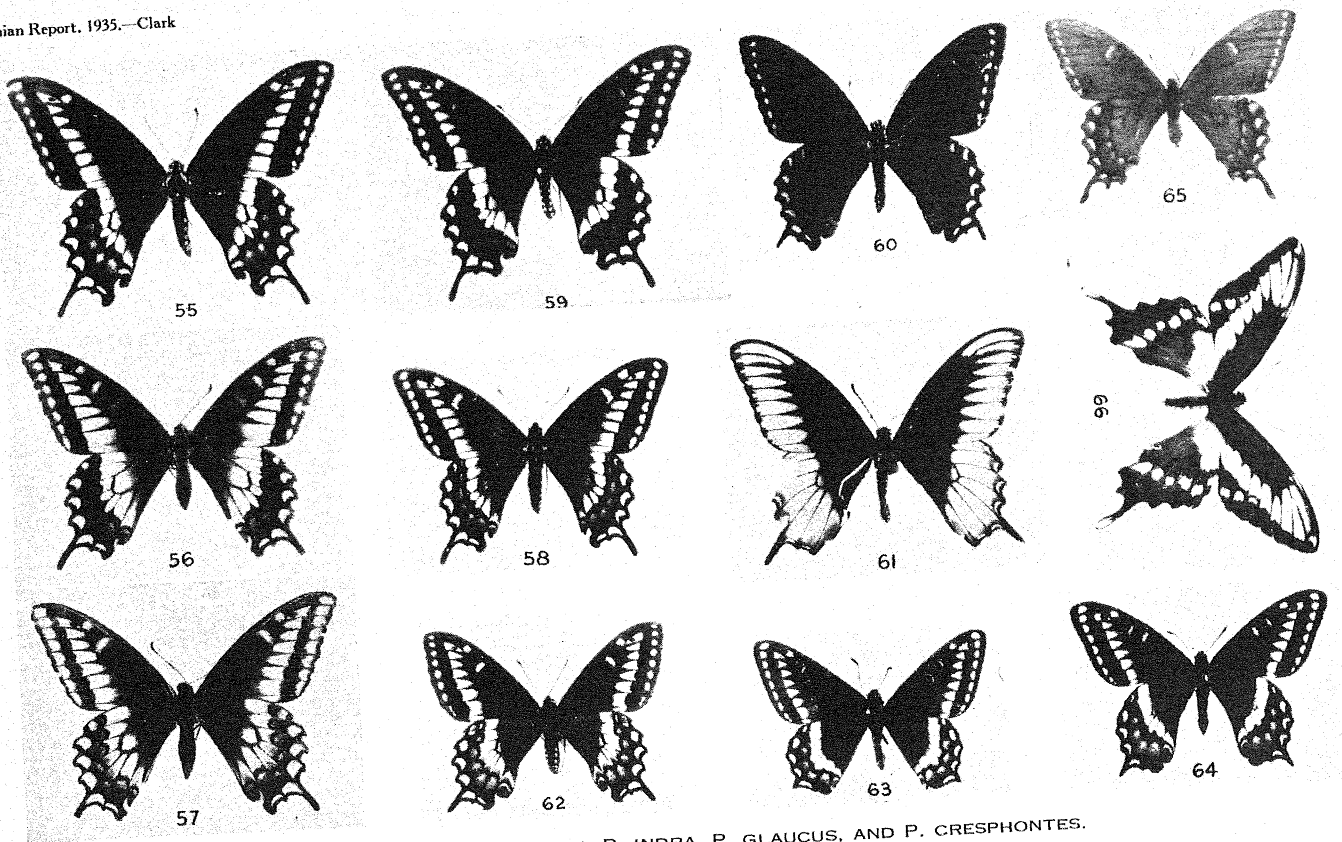
PAPILIO GLAUCUS, P. THOAS, P. ORNYTHION, P. MULTICAUDATA, AND P. PILUMNUS.

(For explanation, see p. 407.)



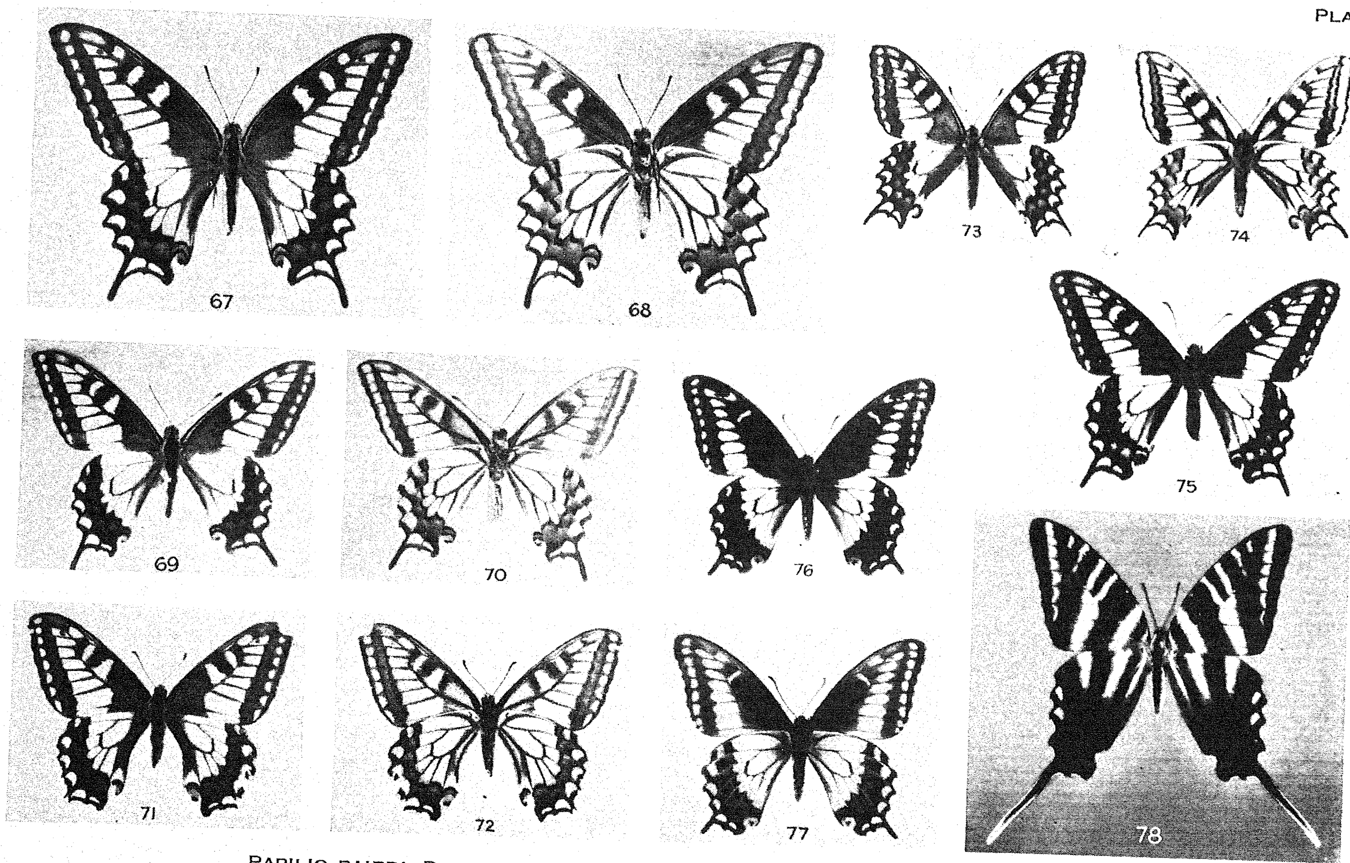
PAPILIO PALAMEDES, P. TROILUS, P. DEVILLIERS, AND P. PHILENOR.

(For explanation see page 407.)



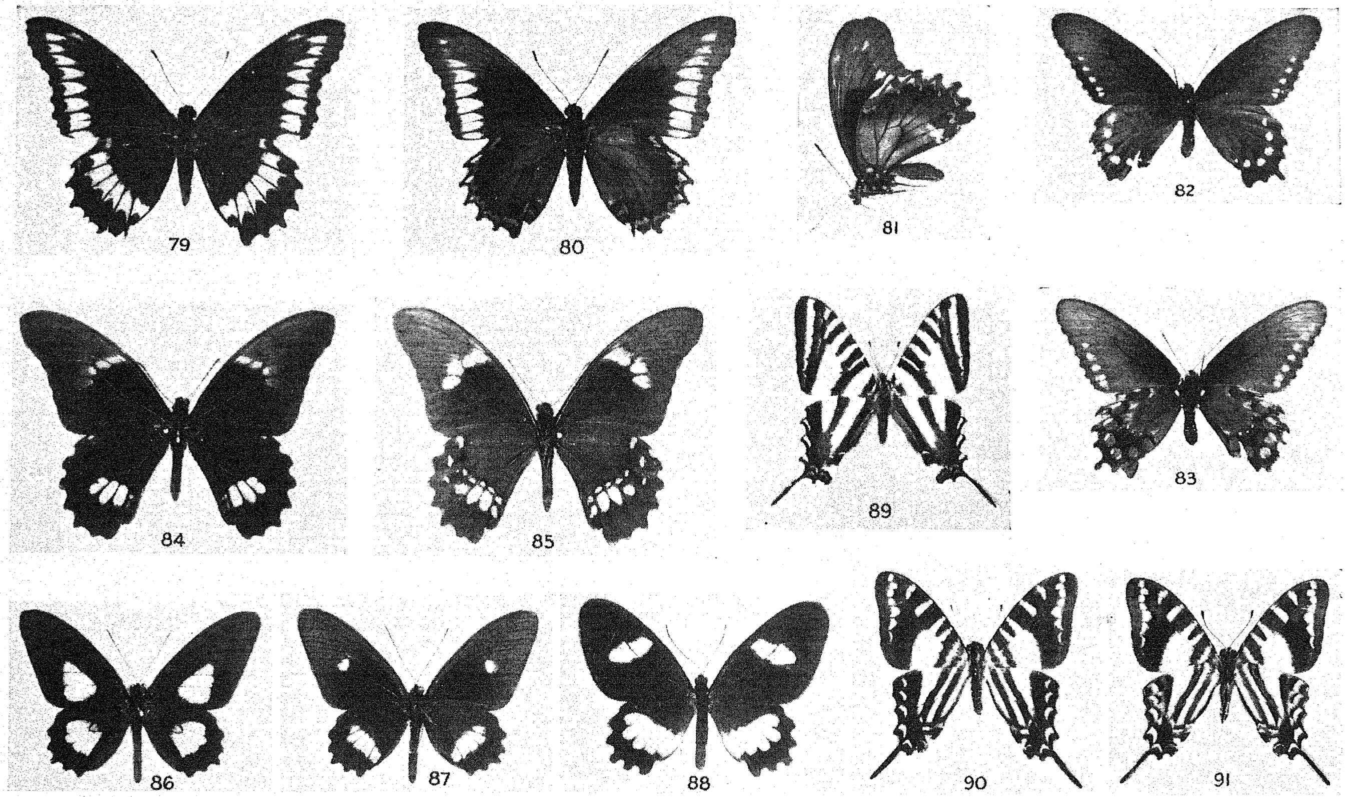
PAPILIO BAIRDI, P. POLYXENES, P. INDRA, P. GLAUCUS, AND P. CRESPHONTES.

(For explanation, see p. 407.)



PAPILIO BAIRDI, P. MACHAON, P. ZELICAON, P. POLYXENES, AND P. MARCELLUS.

(For explanation see p. 408.)



PAPILIO POLYDAMAS, P. ANCHISIADES, P. ARCAS, P. PHILENOR, P. MARCELLUS, AND P. CELADON.

(For explanation, see p. 408.)

THOSE UBIQUITOUS PLANTS CALLED ALGAE

By Florence E. Meier
Research Associate, Division of Radiation and Organisms, Smithsonian Institution

[With 8 plates]

INTRODUCTION

The twentieth century bids fair to mark the completion of man's exploration and conquest of the world. All the lands of the earth from the North Pole to the South Pole, the frozen ice fields and the densely wooded tropics, the highest mountain peaks, deepest canyons, and hot stretches of sandy desert have been viewed by explorers, travelers, or adventurers. Even the interior of the earth has been invaded by means of mines, wells, and caverns. The seas and oceans have been navigated, and divers have plumbed the mysteries of the ocean depths. Aviators and balloonists have flown high into the sky in their search for hidden knowledge.

Wherever man has gone in his wanderings he has always found evidence of life—usually a type of life suited to the characteristic environment. There is the reindeer in the frozen north, the mountain goat surely climbing rocky crags, the prairie dog scuttling about in the plains, the huge boa gliding through the dense tropical jungle, barnacles clinging tightly to the rocks and cliffs by the sea, fish swimming in the fresh and salt waters, the mole tunneling through the earth, and birds flying in the air. The animal life manifests itself more quickly than the plant life, because of its power of movement, its size, and its possibility of being a source of danger. The casual observer might be inclined to estimate the quantity of animal life as greatly exceeding that of the plant life of the globe. Nature, however, always most unexpectedly inconsistent with her whims and surprises, seems either purposefully or otherwise to possess one great favorite group of plants among all her plants and animals, for she has placed visible and invisible representatives of this plant group literally in all parts of the known world. Moreover, she has simplified the moisture, food, and light requirements of this group so that it

will be able to carry on its life processes more easily than the other plants and animals. Wherever the curiosity of man has carried him in his travels, this plant group, the algae, truly ubiquitous in comparison with other live forms, is growing—enormous, as the slimy kelps that are washed onto the seashore after a storm, or minute, as the slime covering the ponds, each cell or individual plant of which is so diminutive that it can be made visible only with a high-powered microscope.

NATURE OF ALGAE

The simplest forms of plant life, the algae, are thallus plants varying in size from a single microscopic cell as small as one thousandth of a millimeter in diameter to a multicellular individual made up of millions of cells and sometimes several hundred feet in length. Algae have no true roots, stems, or leaves like those of the higher plants with which most of us are more familiar. Instead of reproducing themselves by means of seeds, as is customary with the higher plants, these lower plants form new individuals by the division of a single-celled individual into two new single-celled individuals of equal size or by the formation in a cell of the parent plant of spores, which, when released, develop into new plants. The spores may be motile or nonmotile and according to the different species may be produced in number from 4 to 64 or more at a time. The algae, like other plants, possess chlorophyll, or green pigment, and are thus able to make their own food from inorganic materials such as carbon dioxide, water, and certain mineral substances with the aid of light.

The names of the five classes of algae are based upon the characteristic differences in color. These five classes are the green algae, or Chlorophyceae; the blue-green algae, or Cyanophyceae; the yellow-green algae, or Chrysophyceae; the brown algae, or Phaeophyceae; and the red algae, or Rhodophyceae. The brown and red algae contain chlorophyll, but the green pigment is masked by the other colored pigments associated with it.

ENVIRONMENTAL FACTORS FOR THE GROWTH OF ALGAE

The food or elements essential for the growth of the algae are the same as those necessary for the growth of higher plants. Calcium is not essential for many algae, but certain of them are unable to develop in its absence. Calcium, potassium, and magnesium are important because their bicarbonates furnish a supplemental supply of carbon dioxide for photosynthesis, which is the production of sugar from water and carbon dioxide taking place by the action of chlorophyll in light. During this process, a part of the oxygen is set free,

thus providing oxygen for the respiration of animals which in turn throw off carbon dioxide for the plants. Algae also use nitrogen in the form of nitrates, nitrites, or ammonium compounds. A small quantity of iron is essential to their growth. Under certain conditions the nature and quantity of the available calcium, magnesium, potassium, nitrogen, and iron compounds have a direct influence upon the existing type of algal flora, just as the varying diets of the different races of peoples affect their characteristic appearance and habits.

Light, owing to the fact that it is essential for photosynthesis, would seem to be an important factor in the environment of algae. But algae differ markedly in respect to their tolerance of light intensity, as has been shown by our experiments here at the Smithsonian Institution. Provided their food is prepared and in available form, some algae exist in a green condition in the depths of the earth and the ocean with a very small amount of light. The intensity of light that is available for plants growing under water below a depth of 1 meter decreases more or less uniformly with the depth. The turbidity of the water also has an effect on the quality of the light. Water absorbs energy in the infra-red and red region to a much greater extent than in the blue. As a consequence plants in clear water receive a relatively large percentage of light within the region 4400 to 5800 angstroms. Most plants cannot live indefinitely in light intensities too low to permit sufficiently rapid photosynthesis to balance the carbohydrates used up in respiration. The depth at which the compensation point occurs depends on the species as well as on the quantity of light available. The point at which photosynthesis just balanced respiration for certain algae was found to occur from 7 to 20 meters in turbid water and at 30 meters in clearer water. The optimum location for photosynthesis in the lakes of northern Wisconsin was found to be at the surface on cloudy days and at a depth of about 5 meters on fair, bright days. The brown and green algae require higher light intensities for a photosynthetic balance than the red algae. The ability of the red algae to live at greater depths than the green or brown algae may be due to the fact that the red algae absorb a greater percentage of blue light.

Temperature has an important effect on the acceleration or retardation of growth and reproduction, and under exceptional conditions the temperature of the habitat restricts the algal population to certain species.

The quantity of water or moisture necessary for algal growth varies, as may be seen, from the large amount required by the plants that live submerged in the ocean to the infinitesimal quantity at the disposal of the aerial algae.

AERIAL ALGAE

Undoubtedly the algae with which we are all most familiar are the aerial algae or those algae that obtain their water wholly or in large part from the moisture in the air. Strictly aerial algae are found on the bark and leaves of trees, on woodwork, stones, and rocky cliffs. Since atmospheric and hygrometric conditions are of vital importance to these algae, they must be able to survive long periods of drought and recover quickly when given the opportunity to absorb water again. Certain forms have demonstrated their ability to resist drought for continued long periods and have survived in a desiccator for 6 months, then absorbed water rapidly in their dry condition. In districts where severe storms are frequent, aerial algae are not numerous, as they are washed away from exposed woodwork and brickwork. However, they may be found on the ground or lower portions of the woodwork and brickwork where they are protected. Aerial algae usually grow on the shaded side of the support or substrate, but protection from the prevailing winds is probably of greater importance than shade. Certain species of the aerial alga *Prasiola* live only where the substrate is rich in nitrogen. They grow luxuriantly in rookeries and on rocks or cliffs, where they live on the excrement of birds.

Nature is the perfect artist when left to her own devices. In her ardor for beauty she cunningly shrouds old broken-down fence posts, horse troughs, well and cistern coverings, wooden turbine conduits, ditches, roofs, and the detritus of barnyards with the restful and beautiful colors of the algae. In special honor to the whalers and other sea lovers buried in the old graveyards on the eastern coast of New England, she wreathes their dark granite tombstones that are cracked and almost ready to crumble with graceful masses of golden algae. This same alga, which, though a green alga, may appear with different pigmentation in accordance with the nutrient solution or light in which it is growing as shown by our experiments here, covers the red roof tiles of a hut, or sparse soil, and beech trees with bright yellow mats of luxuriant growth. It is a greener color in the shade, and in damp weather it is unusually conspicuous against its dark backgrounds, while on dry days it adheres closely to the surface of attachment. In India, the aerophilous algae produce alternating red, green, and black bands on the bark of *Oreodoxa regia*. The red coloration is due to *Trentepohlia umbrina*, the green to *Protococcus viridis*, and the black to *Scytonema ocellatum*. Another species of *Trentepohlia* is responsible for the rusty coloration of cement and masonry walls.

The Pedras Negras in Pungo Andongo in Portuguese West Africa receive their names from an alga that grows in black stripes on the

rocks following the course of running water. A small alga gives the granite rocks at Rio de Janeiro, Brazil, their brown color, and a blue-green alga colors the lime walls of the precipices of the Rhaetikon Mountains in Austria, a bright blue color. On the Tschmanin-Tal of the Tyrol in Austria, from 1,000 to 2,500 meters above sea level on the west to the southeast sides, the effect of the light intensity governs the appearance of the algae. On the outside of the cliffs nearest the light are the felty masses of yellow and brown *Scytonema* and blue *Gloeocapsa*, while on the inside of the cliffs away from the light the *Gloeocapsa* mats are colorless. On the upper surfaces of stones may appear a bright orange wealth of *Trentepohlia*, while on the lower surface are colorless plants of *Gloeocapsa*. When a chemical analysis was made of the food material obtainable in these rocks for the algae, it was found to be as follows: Calcium oxide, 30.67 percent; magnesium oxide, 21.49 percent; carbon dioxide, 47.2 percent; ferric oxide, 0.22 percent; and manganese oxide, 0.28 percent.

On the inland cliffs of Natal, in Africa, the earliest and perhaps the only possible colonist was the blue-green alga *Gloeocapsa sanguinea*. On the rocks dripping with moisture is also found *Stigonema*, whose yellow, brown, and black threads are almost completely enshrouded with the red coiling filaments of *Schizothrix*. Otherwise, the cliffs are covered with black lithophilous Cyanophyceae. In dry weather these algae shrivel and peel off, thus restoring the original color of the cliffs. The algae have to withstand adverse conditions of drought and cold only during a comparatively short period on these cliffs, conditions that are not so extreme on the Drakensburg Cliffs as in the lower dry river valleys.

A beautiful example of the zonation of algae on cliffs exists on the islands of South Orkney, Ireland. At Green Head the face of the cliffs that look out toward the wrecks of the sunken German fleet is marked with great streaks of color as if by a gigantic paintbrush. Lower seaward, where the waves pound against the shore when the sea is rough, the colors appear in big patches. At the top of the cliff is a black mourning frame of *Verrucaria maura* about 2 feet in depth, then below that in the following order: A yellowish green stripe about a foot deep of *Pelvetia*, a 3-foot band of orange-green *Fucus spiralis*, long straplike fronds of olive-yellow *Ascophyllum nodosum* and *Polysiphonia fastigiata* extending for 3 feet in depth, dull green patches of *Fucus vesiculosis*, and *Fucus serratus*, distinctly green in the light though dark in the shade, spreads itself out over the flat stones near the low-water mark. Truly this is a colorful monument that nature has raised.

TERRESTRIAL ALGAE

It is difficult to differentiate between aerial and terrestrial algae on the basis of source of water, since many of the terrestrial algae live below the surface of the soil. The number of soil-inhabiting algae is very large; some of the forms are strictly terrestrial, but most of the species are also known in aquatic habitats. In many parts of the world the terrestrial algae form a conspicuous coating on the soil only during prolonged rainfall, when the soil is continually saturated with water. In middle-western sections of the United States, the extensive development of soil algae is restricted to especially rainy years. In California, there is a regular development of them during the rainy winter months.

These algae usually grow on the soil in small patches, a few inches in diameter, a number of species in each patch. Sometimes, however, they cover large areas an acre or more in extent that consist very largely of a single species. The texture and chemical composition of the soil determines the particular species present as may be seen by comparing the algae growing in a well-beaten path with those growing on bare loose soil next to the path. The influence of the chemical environment may be exemplified by the restriction of *Zygogonium* to acid soils and the development of *Prasiola* on damp soil rich in nitrogenous matter.

Nature reserves a utilitarian purpose that is threefold for her terrestrial algae. They aid in the erosion of exposed surfaces, their decay affords the first available supply of humus, and they provide a moisture-retaining substrate for the spores and seeds of higher plants. Microscopic green algae such as *Gloeocapsa*, *Gloeothece*, and *Aphanocapsa* in visible green masses are generally the first algae to appear in the colonization of rock surfaces. These algae are followed by filamentous mats of *Scytonema*, *Hapalosiphon*, and *Stigonema*.

After heavy rains, as in California, the green soil-dwelling algae appear as if by magic on the earth. It would almost seem to a casual observer that they came down from the sky with the raindrops. Like the aerial algae, the soil-dwelling algae are able to withstand prolonged desiccation. Many of these algae survive the dry season in a resting condition. Their cell walls become enlarged during the dryness, and the cell contents are thus protected in the decreased center of the cell. The length of time that soil algae can survive desiccation is almost beyond belief, for some of them are able to resume growth after drying for 50 years.

Certain algae are able to build up chlorophyll and phycocyanin and to grow in the dark, provided sufficient food material is available. Green filamentous algae have been found growing on the

dripping rocks among the stalactites and stalagmites in the dark caverns at Luray, in the Blue Ridge Mountains of Virginia. There is an abundance of calcium carbonates there for the nutrition of these algae. The only light that they receive is occasionally when electric lights are turned on for a short time each day as visitors pass through the caverns.

The algae that grow in the soil act as agents for the transformation of the ammoniacal substances already present into more complex organic substances. They thus aid in bringing about the nitrogen cycle of the soil and in keeping up the gas balance. By their death, the algae contribute largely to the fertility of soils in that they present quantities of organic material to putrefactive bacteria for decomposition. They are also a source of food for Protozoa and worms. The mucous vestments that encase so many of the soil algae help the soil to retain its moisture. The subterranean algal flora is generally restricted to the upper 18 inches of the soil, although algae have been found at a depth of 8 feet below the surface.

AQUATIC ALGAE

Aquatic algae of fresh-water habit are of four general types, corresponding to the following habitats: Bogs and swamps, pools and ditches, ponds and lakes, and flowing waters. The algal flora growing in gelatinous masses on submerged plants and in the water of bogs and swamps is varied and rich in quantity. A drop of bog or swamp water when examined under the microscope reveals a fairy-like world of beautiful colors and curious forms. There appear miniature spheres colored different shades of green, yellow, gold, brown, and blue-green; sometimes there appear globes that are massed together or enclosed in gelatinous envelopes, little green new moons arranged singly and in clusters, tiny nets of green, fantastically shaped accordions, small green clubs sometimes joined together end to end like pieces of iron on the end of a magnet, little green stars, and minute masses and balls that seem spiked in all directions with bristles like a pincushion full of pins. In and about the drop, like the background of a tapestry, are beautiful straight, twisted, coiled, and spiral green and yellow threads. The whole drop seems to be in motion as the different forms dart quickly, glide gracefully and slowly, or jerk about in the water. Some of the balls seem to explode before the eye, releasing in all directions their diminutive green replicas.

Many species, such as *Ophiocytium* which, like Proteus, is noted for its gift of transformation, flourish best in rain pools that become stagnant and foul in hot weather. They prosper when there is little aeration of the water. *Ulothrix idiospora* and *Tribonema*

bombycinum are also peculiar in this respect. Some of the most beautiful microscopic species may be found in the dark, dank, rain-covered interiors of funeral urns in cemeteries.

Inundated rocks in bogs and swamps give more aeration with, at the same time, a maximum of humidity for the growth of many algal forms.

Some swamps vary in their quantity of water during the year, as in the spring at flood times and again in the summer when they may dry out until only small puddles of water are found around the tufts of grass and swamp plants. The algal flora changes often according to the quantity of water present, and in the winter time certain species may be found under the ice.

Variation in the gases formed in bogs, swamps, and ponds has its effect on the predominance of type of algal flora growing there. Large gelatinous masses of green and brown algal cells are generally formed on the bottom of the pools and then floated up to the top by the oxygen developed during photosynthesis. Less oxygen is, under ordinary conditions, developed by the larger masses of blue-green algae that remain on the bottom during the whole vegetative period. During hot, still, summer weather, when there is little circulation of air about a pond or pool, the carbonic acid manufactured by the bacteria at the bottom of the pond is not equally distributed through the water, thus depriving the algae of their food. The blue-green algae then tend to rise to the top of the pond for better aeration and form a film of green or yellowish-green scum that is commonly known as water bloom or frog spit.

During one summer at the Weequahic reservation of the Newark park system, in New Jersey, unusually large numbers of algae were formed in the lake. One night, all seemed to be serene about the lake, but the next morning at least 15 tons of dead fish had appeared. Bass, roach, sunfish, catfish, suckers, eels, and even a few carp were found floating dead in all parts of the lake, but in especially large numbers near the inflowing brooks. Instinct had evidently driven them to seek fresh water entering the lake. At the clear spring in the center of the lake there were some living fish. For a time the authorities were considerably puzzled over this mystery of the dead fish. Had the lake water been poisoned or dynamited? The remaining live fish were gulping air at the surface of the lake. Others had died with their mouths open. It was finally agreed that the fish had died of suffocation. There was found to be an insufficient supply of oxygen in the lake. At a depth of 1 or 2 feet there was practically no oxygen. The algae were decaying and settling to the bottom of the lake.

Meterological conditions were responsible for the tragedy. The weather had been extremely warm and the temperature of the water at the surface was 82° F. The humidity was high enough to prevent evaporation from the surface. There was so little wind that the lake was as calm as a mirror. The algae tended to rise to the surface and form a scum there. Concentrated at the surface, their food material became exhausted as, owing to the warm weather and the intense summer sunlight, the algae had developed to such an extent that there was not enough carbonic acid in the lake to supply them. The majority of algae flourishing at this time of year are the blue-greens, which are much less powerful oxygenators than the green forms. The lake was overstocked with fish, which, lacking a sufficient supply of oxygen, died of suffocation.

A short time after the death of the fish, a breeze sprang up, then a heavy wind, restoring oxygen to the lake, especially to the end toward which the wind was blowing. With the decay of the blue-green algae, which to a large extent were *Anabaena* and *Clathrocystis*, the type of algae changed to the green forms such as *Scenedesmus* and *Raphidium*. These latter forms contain chlorophyll and are strong oxygenators. They developed with such rapidity that the oxygen in the water was increased beyond the point of saturation. Plenty of carbonic acid was then derived from the decay of the carbonaceous material at the bottom of the lake, for when the water is in circulation the carbonic acid manufactured by the bacteria at the bottom of the lake is distributed through the water, giving food to the algae. There are always less blue-green algae in water that is in constant circulation.

Just as an acre of land will support a certain plant population, a given volume of water will support only a certain number of plants. Intense light is bad for algae, but the blue coloring matter in the blue-green algae helps protect their green pigment, so that more blue-green algae are found on the surface of a lake on the hot, sunny days of summer, and the green algae are farther below the surface. Deep cold lakes of the north rarely are covered with water bloom.

In Alberta, a report was made of cattle being killed by the water from a lake covered with water bloom. The owner thought that his slough had been poisoned with paris green when he saw the water covered with the oily green masses of *Gloeotrichia pisum*, which gives the water an opalescent or iridescent appearance. As in other districts, the horses, cattle, hogs, poultry, and even wild birds were seemingly poisoned by the water from these lakes, the aborigines called them poison lakes. The algae may be the indirect cause of the death of the animals as seen from the example of the fish given

above, although the real cause was probably the exhaustion of oxygen and the poisons given off by putrefactive bacteria during the decay of the abundance of organic matter present.

It is hard to believe that cattle can be killed in this manner. When one is riding by train through the country in August and September, again and again flashes upon the vision scene after scene of cattle peacefully resting beneath the trees and chewing their cuds beside the still ponds covered with apple-green water bloom, or frog spit, as the farmers call it.

The common fresh-water alga *Botryococcus* frequently forms water bloom. The radially arranged green spherical cells are embedded within a tough, sometimes orange-colored mucous envelope, which is folded or wrinkled and frequently drawn out into irregular lobes or spines. The deposits formed by this alga are distinguished by a slow rate of decay and are sometimes responsible for considerable sapropelic accumulations (the slimy sediment of organic debris derived from aquatic plants and animals). Various authorities believe that the Paleozoic remains (*Pila*, *Reinschia*) found in boghead coals are ancient allies of *Botryococcus* and that such coals were to a great extent formed by them.

Odors of the algae may interfere with the lake as a recreational center. Often they affect the taste of reservoir water. Not until the middle of the past century was the practical significance of the study of organisms in water realized. Dr. Hassall, of London, England, was the first to call attention to the value of microscopic examinations in the interpretation of drinking-water analyses. About the same time, Ferdinand Cohn (1853), working on the Continent of Europe, wrote his treatise entitled "Living Organisms in Drinking Water", in which he indicated the correlation between aquatic life and water purity. To the Massachusetts State Board of Health belongs the credit of having begun as early as 1887 a systematic examination of all the water supplies of the State.

Myriophyllum and a number of the filamentous algae possess a natural odor that gives a strongly vegetable and at times almost fishy taste to the water. The colonies of the alga *Synura* give a strong cucumber taste to the water. Algal odors are sometimes strong enough to be sensed in the vicinity of reservoirs. In some cases the odors have been wafted by the wind for distances of a quarter of a mile. The decay of littoral growths of filamentous algae may cause objectionable odors along the shore. The odors derived from the exposed bottoms of reservoirs when the water has been drawn off are familiar to all of us, but it is not generally known that these odors are largely due to algae. Sometimes algae are blown inshore by the wind and stranded on beaches where they decay and produce

foul conditions. The "salty sea odor" so much loved is largely due to stranded seaweed or marine algae.

The best way to eliminate odors and tastes produced by algae in lakes, ponds, reservoirs, and other standing bodies of water, is to control the growth of the water plants, in the place concerned. Numerous methods have been devised to accomplish this, some of which are: Reduction of the available food supply, or by so modifying the chemical composition of the water that it will not support large growths of algae; poisoning the organisms by the addition of chemicals to the water; and control of the physical factors that affect the growths. The use of copper sulphate as an algicide has become standard practice. Ordinary commercial crystals of blue vitriol are placed in a coarse bag or gunny sack. The container is attached to a rope and drawn zigzag back and forth across the water at the stern of a rowboat. Organisms differ considerably in their susceptibility to copper sulphate. Some of the blue-green algae are destroyed by the application of only 1 part of copper sulphate in 10,000,000 parts of water.

The rice fields of southern Spain and Samarkand with their irrigation ditches contain numerous algae characteristic of tropical and subtropical flora found in sluggishly flowing water or in hard, strongly mineralized waters of pools and bogs (pl. 1, fig. 1). These algae demonstrate their ability to withstand great differences in temperature changes during the day. The daily temperatures vary in June and July from 68° to 99° F.; in August and the early part of September from 61° to 84° F. The increase and decrease of algal forms are proportional to the periodicity of the irrigation.

In a large body of fresh water, as was found to be true in the central African lakes, a single sample of the algal flora obtained in a stated locality cannot be regarded as representative of that of the entire lake. Collections of algae made within a few days of each other from different parts of Tanganyika differ radically even in their dominant type of flora. It seems probable that in large lakes the different species of algae occur in large shoals of more or less limited extent.

Algae are common in torrential brooks and rivers (pl. 2, fig. 2). The river may possess its own typical algal flora, or algae may be carried into it from springs, pools or ponds, lakes, canals, or tributaries. The factors governing the algal production in a river are the rate of flow, the detritus content, the quantity of water, the chemical constituents, and the temperature. Except in certain very large rivers, the swifter the current, the less the algae. As a river flows through various lakes the algae of the river are modified by the lake through which it passes, just as the algae

of the lake in turn are modified by the river passing through it. For this reason a long river passing through country with great variations in the altitude and in the other factors mentioned above can exhibit interesting and varying algal forms in different points of its course.

The algae growing in hot springs have become adapted to life under high temperature conditions, and some of them can live and grow at temperatures as high as 167° F. All these so-called "strictly thermal algae" are blue-green and grow within the hot springs as well as in the outflow from them. The best known and most thoroughly investigated of the thousands of hot springs in the western part of the United States are those of the Yellowstone National Park. Practically all the thermal algae are species that have become acclimated to hot springs and that are not found elsewhere. The waters of the hot springs are highly charged with soluble calcium and magnesium compounds, especially bicarbonates. Much of the lime deposited there results from the evaporation and cooling of the water. However, most of what the geologists call "travertine", or the material deposited, is due to the action of the abundantly present algae or their chlorophyll in consuming or decomposing the carbon dioxide that is present in the water and thus reducing the amount of calcium bicarbonate that may be held in solution. The precipitated lime is a byproduct of the photosynthesis of the little plants. The travertine may attain a thickness of 2 to 4 millimeters in a week. The terraces of travertine thus formed are usually brilliantly covered by the overlapping layers of algae, which are bathed by intermittent discharges of highly mineralized fizz water.

Hot springs are not the only places where the algae aid in the deposition of calcium carbonate. The stones of the Scottish lakes in winter are covered with a rich brown coating of diatoms, which in summer often disappears. In several lakes, its place is taken by a crust of grayish lime deposited from the blue-green algae. The same occurrence has been noted in the Swiss lakes.

In 8 feet of water on the sandy bottom of a Michigan pond that is separated from Lake Michigan by a sand bar, curious hollow pebbles 1 to 3 inches in diameter with a stratified or concentrically zoned structure were picked up. Upon decalcification, these pebbles were found to be composed of a densely interwoven mass of bluish-green filaments, species of the algae *Schizothrix*, *Stigonema*, and *Dichothrix*. The colony of algae evidently starts at some point of attachment such as a shell and then grows out radially in all directions, each filament independent of the others and all of them precipitating calcium carbonate tubules. The tubules are strong enough

to serve as points of attachment for other plants. The ellipsoidal pebble, really belonging to the vegetable kingdom, to the casual observer is in nowise different from an ordinary rounded pebble.

Marl deposits at the bottom of shallow lakes are thought to be almost wholly due to the action of the blue-green algae.

Just as the Eskimos can live and prosper in the frozen north, so nature has equipped species of algae to live in the ice and snow. In the Swiss Alps, the Pyrenees, the Carpathians, the Urals, the Sierra Nevadas, the Andes, and in the mountains of Scandinavia and Greenland, where large areas are covered with eternal snow, these hardy little plants may be found coloring the old snow with a rosy tint of great beauty, or sometimes in such abundance that they look like blood stains. The motile stage of the algae is confined to the thawing surface. Generally they are on rather hard, more or less permanent snow of which the surface is somewhat wavy during the thawing period, and the algae are found in the wave troughs, which they undoubtedly accentuate because of their ability to absorb the heat rays. Sometimes the algae are only faintly visible through the upper layers of snow where they are about an inch or so under the surface. They are especially conspicuous in large fields of soft snow where their faint tinge leaves bloody traces when walked upon. Mineral dusts, pollens, or seeds help to increase the absorption of the heat rays and prepare better conditions of life than exist on the quite bare surface of the snow. *Sphaerella nivalis* and varieties of *Cystococcus* are the algae most commonly known as "red snow." A temperature above 39° F. is harmful to these particular varieties.

There are other varieties that color the snow yellow-green or green, though it is generally supposed that the young cells are yellow-green and green, and that as they grow older the haematochrome or red pigment develops and masks the green pigment. Various hypotheses concerning the physiological adaptations enabling snow algae to grow at low temperatures have been based upon the storage of reserve food as fats and upon the haematochrome functioning as an absorber of heat rays. In experiments at the Smithsonian Institution I found that the red pigment formed in *Haematococcus pluvialis* when the alga was exposed to intense continuous illumination for a month, whereas in intermittent light the pigment remained dark green, and in continuous darkness reddish brown. The greatest amount of growth took place in the intermittent light, and the least amount in continuous darkness.

The marine algae or seaweed receive the earliest mention in our histories. Humboldt relates how the Phoenician mariners came to a place where the sea was covered with rushes and seaweed. The seaweed is

uncovered at ebb and overflowed at flood tide. *Fucus natans*, apparently floating unattached, was described by Columbus as *Sargazo*. In the North Atlantic, the sailors with Columbus, seeing great olive-colored masses of it, thought that it was land. The mariner soon learned that it tails a steady wind, and thus he knew when he found it whether the wind had been blowing in the observed direction for some time. The Sargasso Sea, famous in early explorations, was named from the alga *Sargassum*, noted for its beauty and grace of form. Its lacelike branches are due to minute species of *Campanularia*, *Plumularia*, and *Sertularia*. *Sargassum* is commonly found in both the Atlantic and the Pacific Oceans, and in tropical and subtropical seas.

The character of the marine algae is determined by salinity and temperature of the water, light intensity, and the nature of the ocean floor for attachment. The continued existence of the marine algae depends upon their ability to cope with enemies. Their greatest enemy is doubtless the mechanical action of the water during storms, after which the shore is fringed with plants ruthlessly torn from their places. Seaweeds are adapted by structure to yield to or to resist the constant action of the water. Strong holdfasts allow the long and flexible varieties to wave harmlessly back and forth. Stiff, low, and round kinds permit the water to flow over and around them. Practically all seaweeds grow on the sides, upper surfaces, and crevices of large rocks and bedrocks; some grow on stones not longer than 5 centimeters, and a few on the under side of stones.

If sand is shifted in large amounts by water currents, it beats against the algae and buries and kills them. Fishes use seaweed for their food, and this appreciably affects the quantity of some kinds. Many of the larger seaweeds and corallines are protected by secretions of lime, but some fishes even eat the corallines. One authority studying Hawaiian fish food found that no fish is strictly herbivorous and the majority are carnivorous. Many eat some algae. The fish were divided into four groups according to their food: Plankton feeders, bottom feeders, shrimp feeders, and carnivores. Algae were found in the stomachs of all the groups except the shrimp feeders.

At times, oceans receive their coloring from the algae that are abundant in their waters at a particular time. Some of the tropical marine forms are phosphorescent. A greenish-brown discoloration of the sand of seashores due to certain species is common after the tide has ebbed.

SYMBIOTIC AND PARASITIC ALGAE

Many algae are found living in association with specific plants or animals. A true symbiosis exists when each member of the pair living together contributes to the mutual support. The lichens are the most

interesting example of symbiosis. Lichens are composed of green algae that live within the colorless filaments of fungi. Possibly neither plant could exist alone on the hot bare surfaces of rocks where we so often find them growing in beautiful rosettes of various colors and on trees. But together each helps supply the needs of the other. The fungi absorb and retain moisture from the air, while the algae by means of their green chlorophyll carry on the photosynthetic activity necessary for the double existence.

Algae may grow in symbiosis with diatoms, with other algae, and with higher plants. In the case of the alga *Anabaena cycadeae*, growing in the roots of the higher plant *Cycas*, a true symbiosis exists. The algal cells in the nodules are soon surrounded by nitrogen-fixing bacteria of the soil. The leaves of the higher plant obtain energy from the sun and manufacture carbohydrate food material not only for the plant itself but to supply the bacteria which make nitrogenous material available to the alga. In some cases of symbiosis, the two plants, though living in close association, seem to have neither a harmful nor a beneficial effect upon each other.

Codium bursa, which is found in northern seas as well as warmer ones, appears to harbor a flora and fauna all its own. It has a large spherical thallus with a fluid-filled interior cavity. When the thallus is ruptured, the fluid gushes forth as if under considerable pressure. This fluid is more saline than the surrounding sea water. Lining the interior cavity, especially near the base, is a reddish mucus consisting of blue-green algae (mostly filamentous forms), numerous diatoms, microscopic animals, and worms. Some of the species are peculiar to this habitat. Their reddish color is correlated with the feeble violet light at the depth of 14 to 40 meters at which they live.

Algae also grow in one-celled animals, as the blue-green algae that color amoebae and other Protozoa. They also grow in symbiosis with small marine animals, mollusks, and insects. One species of *Rhopalodia* grows in thick, yellow-brown, matted masses on the back of a beetle, *Limnogeton*, on tropical lake shores.

Most people are familiar with the term "mossback" as applied to the common snapping turtle, or perhaps have noticed turtles covered with green "moss." In reality, this green moss is a mass of green algae. The shell of the turtle and the mud that settles upon it make an excellent habitation for aquatic green algae, while in return for their ideal living conditions they render the turtles as inconspicuous as old rotten logs. Turtles have been seen with filamentous algae attached to their shells sometimes in tassels fully twice as long as the turtle. As the turtle swims along, the green filaments trail out behind it in a most attractive manner. In general, the algae found

decorating the backs of turtles belong to the two species *Basicladia crassa* and *Basicladia chelonum*.

Algae grow commonly on the long, thick hairs of the dense coat of the three-toed sloth in the Tropics (pl. 2, fig. 3). This animal loves the coolness and the shade, which it seeks in the tops of trees, thus furnishing ideal conditions for the bright green algae growing on the hairs and helping to conceal it among the leaves. Large numbers of minute microscopic unicellular algae grow in dense colonies in the crevices of the elongated scales that, under the microscope, are seen to lie singly overlapping the hair shaft. Two genera of algae have been described that grow on *Bradypus*, the three-toed sloth, and on *Choleopus*, the two-toed sloth; they are the green alga *Trichophilus welckeri* and the red alga *Cyanoderma bradypodis*. Here at the Smithsonian Institution, in the collection of skins of the division of mammals in the United States National Museum, I have abserved the algae in a dried green condition on hairs of sloths from Costa Rica that were killed 60 years ago.

Algae may also cause harm or injury to the plants or animals on or within which they are growing. The alga *Nostoc* penetrates through the stomata of the tissue of certain liverworts, then breaks up and destroys the neighboring cells of the host plant as it makes its exit through the tissues of the host. *Nostoc* also grows in the spiral filaments of *Sphagnum* moss. *Hydrodictyon*, the alga commonly known as the water net, has been found about an unlucky dead fly, which it had undoubtedly entrapped. Filaments of an *Oscillatoria* have been found growing within the intestinal epithelium of the carp; also colorless algal parasites have been found in the caecum of the guinea-pig, the pharynx of the hen, the mouth of the horse, pig, sheep, and goat, and in the intestines of man. As an adaptation to parasitism these algae lose their chlorophyll, since their food is supplied them in the desired form without the necessity of their manufacturing it themselves.

The great fondness of some algae for calcium makes all shell-bearing animals open to attack from the calcareous or perforating algae. Often on the seashore, we find shells covered with little gray and green spots like the spotted petals of the guinea-hen flower. These little spots are not only on the surface of the shell but extend deep into it until the shell sometimes is corroded completely by the ramifications of these calcium lovers. The same alga, *Siphonocladus voluticola*, often responsible for this destruction, is found in both salt water and fresh water.

These perforating algae are found from the cold seas of the north to the extreme south of Cape Horn, in all the European seas, on the eastern and western coasts of America, and in the Tropics of Africa,

Asia, and America. They perforate calcareous substances of all sorts from the Bryozoa and the tubes of worms to the strongest rocks. They are responsible for the blue and green spots on the calcareous rocks of the coast, spots that may extend to 50 meters in depth. They are especially common in the superficial layers of the zone inundated by the waves of the sea, where they work in concert with perforating animals such as sponges and mollusks.

Not only animals, but calcareous algae such as *Lithothamnion* undergo attacks from perforating algae. In the rivers of northwest Russia the dissolving action of the perforating algae is exercised not only on calcium carbonate, which they transform into bicarbonates, but also on magnesium carbonate. This often accompanies calcium carbonate in mollusks and corals. The perforating algae have a very ancient origin, dating back to the Silurian epoch, as shown by evidences of their presence in fossil mollusks and fossil bones of animals.

The coral reefs of the Red Sea, Ceylon, Java, and the Bahama Isles have suffered from the destructive work of the perforating algae. They invade not only the debris and the coralline sand but also blocks detached from the banks and the coral reefs. The lower part of the coral is often pierced by a whole canal of *Ostreobium reinekei*, which will bring about the rupture of the coral in this place by the shock of the waves. It is certain that perforating algae contribute to the formation of the atolls in taking part in the destruction of the central part of the coral banks. It has also been suggested that the factors controlling the depth at which reef-building corals can live may be determined by the suitability of the conditions for the photosynthesis of the algae associated with the coral formers.

ALGAE GROWING IN A VACUUM

Since algae grow in the soil, on the ground, on plants and animals, in the water, in the air—in short, in every conceivable natural habitat—two scientists wondered if possibly they might grow in a vacuum. Consequently they selected 48 species of the simplest forms and, supplying them with a sufficient amount of nutrient solution, placed them in a hermetically sealed bell jar from the inside of which all traces of oxygen and carbon dioxide were removed. They placed the bell jar in artificial light for 40 days. Of the 48 species, 10 were incapable of developing in these conditions, but their growth subsequent to the removal of the bell jar proved that they had not perished. Thirty-eight species developed in the vacuum. Those algae that withstood the conditions especially well were aquatic species. The vacuum prevented the production of chlorophyll, starch, carotin, and xanthophyll.

DISPERSAL OF ALGAE

The distribution of similar species of algae in widely separated geographic areas can be explained by the adaptability of algae to various modes and methods of transportation. Possibly one reason algae are so cosmopolitan is that they are good travelers and ready to seize every opportunity for making a voyage. It is generally assumed that the vegetative cells of algae cannot survive desiccation and would perish during transportation through the air. Recent studies on the viability of algae in desiccated soils have shown, however, that many algae that have withstood desiccation for years have no sporelike stages. It is probable that dissemination of vegetative cells is of far greater importance than that of spores.

Streams assist greatly in the transportation of algae. The distribution of many species of marine algae is due to the ocean currents. The two major agencies of transportation are birds and the wind. The swimming and wading birds, such as sea gulls and ducks, carry the algae in the half-dried mud on their feet. Lodging among the feathers of the birds, the algae are carried about with them also. Migratory aquatic birds carry algae from one lake to another. Recent airplane and Zeppelin studies of the spores contained in the air have shown the presence of algal cells in the air above the plains as well as over the cold stretches of Labrador and the great ice cap of Greenland. Many algae have been found among the mineral particles and diatoms carried in the great dust storms of the northwest that have left the snow tinged with a grayish coating. Dust clouds originating in Arizona and New Mexico or in the western portion of the Great Plains of the United States have been known to travel east of the Mississippi River before falling to earth. Among the dust particles the algae are thus carried more than a thousand miles from their native habitats. The rain aids in washing the spores of algae to places far from the parent cell. The presence of many species of algae common to the southern and western coasts of Australia on the Atlantic and Mediterranean coasts can be explained by the fact that they were carried there by ships. In the case of *Asparagopsis armata*, the hooks and organs of permanent attachment, which are barbed branches, fasten themselves on parts of the ship. Often when tropical higher plants are introduced to aquaria, they bear in their leaves small algae that adapt themselves to their new environment. At Kew Gardens, in England, many species from South America and Egypt have been introduced in this manner.

USES OF ALGAE

Some of the uses of algae have already been mentioned. Probably one of the greatest uses is as food for fishes. Fishes are dependent

upon algae as direct or indirect sources of the oils and vitamins of their food and energy. In turn, through the game fishes, the algae constitute indirect sources of food and energy for the human race. One scientist studied the algae in 5 ponds by making a collection and investigation of the intestinal contents of 100 tadpoles in each pond at 4 different intervals during a year. At the same time the tadpoles were collected, an equal number of pond collections were made. From all the pond collections and tadpoles, 170 species of algae were obtained. In every case except two (in these they were equal), the number of species obtained from the tadpoles exceeded those obtained from the pond collections. This was noticeably true when the ponds involved were large. These results indicate that the algae found in the intestinal tract of the tadpoles serve as a reliable index to the algae of ponds from which the tadpoles were taken.

On the Pacific Coast marine algae such as *Laminaria japonica* are used for the manufacture of iodine. *Gelidium cartilagineum* is harvested on southern and Lower California shores and converted into an improved and purified grade of agar at San Diego. The chemical and physical properties of agar make it applicable to industrial use as a thickener or jelly producer. It is used extensively as a culture medium in bacteriological work, for sizing cloth, and to make candy, breakfast foods, and fancy jellies. Agar is imported from Japan to the United States in large quantities. The Japanese agar is made from various species of *Gelidium*, *Gracilaria*, and *Eucheuma*. The large kelps possess a high percentage of potassium salts, so that when the foreign supply of potash was cut off during the World War, several firms under Government subsidy harvested great quantities of kelp and produced the needed chemicals, but with the end of the war the business gradually declined. At the present time there are two concerns using kelp in California. One of these produces chemicals and fertilizer, the other makes products which are marketed for human consumption, for stock feed, and for fertilizer. The four species of kelp used commercially in California are *Macrocystis pyrifera*, *Nereocystis luetkeana*, *Pelagophycus porra*, and *Alaria fistulosa*.

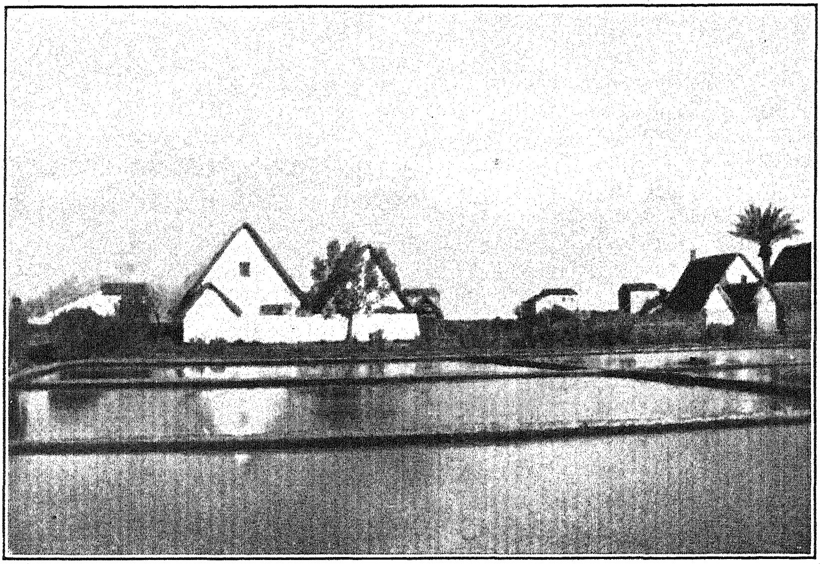
As food for human consumption, seaweeds have long been in use in various parts of the world. The Chinese and Japanese, in their continually losing race between their population and food supply, cultivate various forms of algae for food. The Chinese use a great deal of seaweed, and for the past 40 years they have gathered seaweed on the California coast for export to China. The only local seaweed utilized directly as human food today is *Porphyra perforata*, which is found on the Pacific coast from the State of Washington to Mexico. It also furnishes food for the abalone and the sea slug.

CONCLUSION

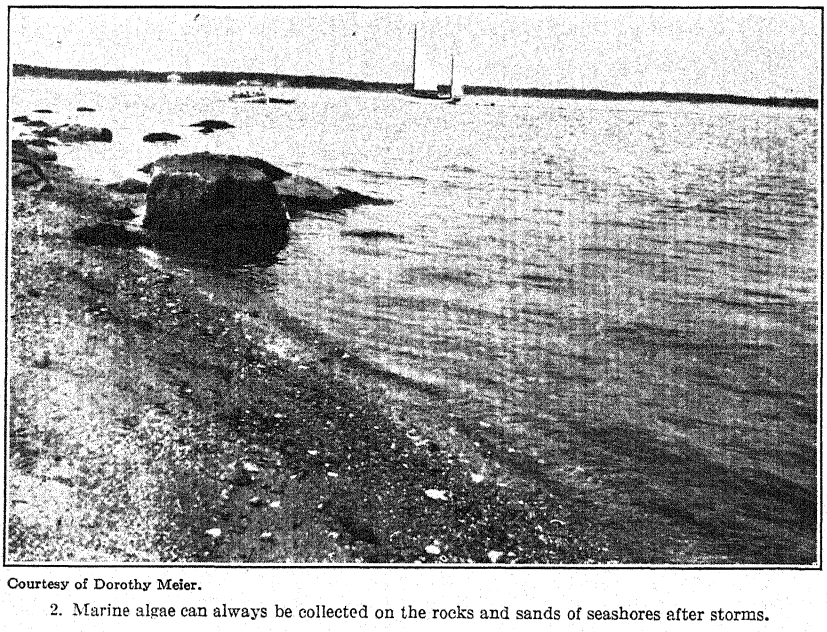
Just as the higher plants vary in size from the tiny chickweed to the oak tree, so we have found a variation in algae from the microscopic unicellular *Cystococcus* to the giant kelps of the ocean. The number of species is legion. It would require too much space to explain how the life cycle of the algae shows almost every conceivable variant. Algae exhibit an enormous range in structure, reproduction, and life history. They include the simplest unicellular forms as well as elaborate multicellular organisms displaying a considerable measure of division of labor. Perhaps nature was experimenting with this cosmopolitan group of plants, as she placed them in every type of environment. Possibly she learned from them how best to construct her more uniform and more complex group of higher plants.

NOTE.—Owing to its considerable size, it was found necessary to omit the list of literature consulted in writing this article.

The specimens of algae shown in plate 4, figure 2, and plates 5–8 are in the United States National Herbarium.

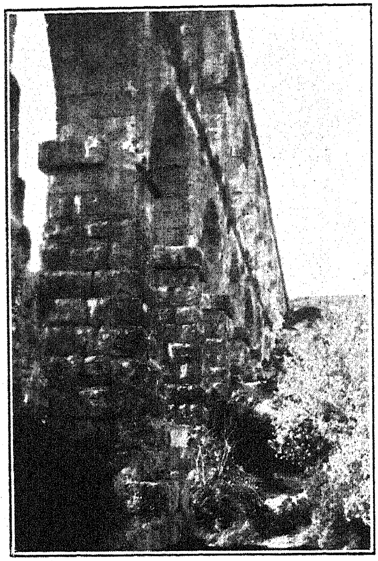


. A wide temperature variation produces an interesting group of algae in the rice fields when covered with water and at other times in the irrigation ditches near Valencia, Spain.

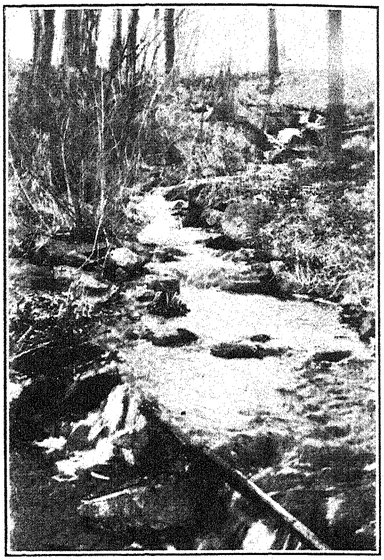


Courtesy of Dorothy Meier.

2. Marine algae can always be collected on the rocks and sands of seashores after storms.

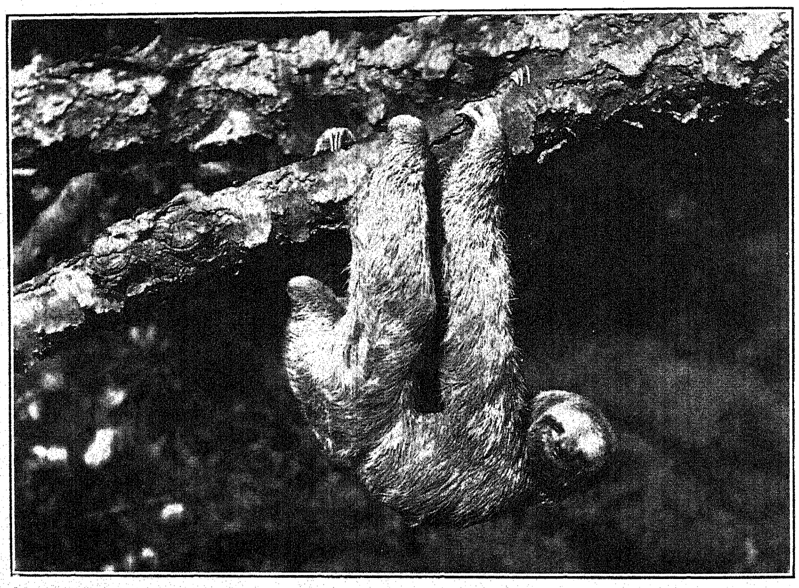


1. The stones of the old Roman aqueduct, known as the Bridge of the Devil, in Tarragona, Spain, are spotted with patches of aerial algae.



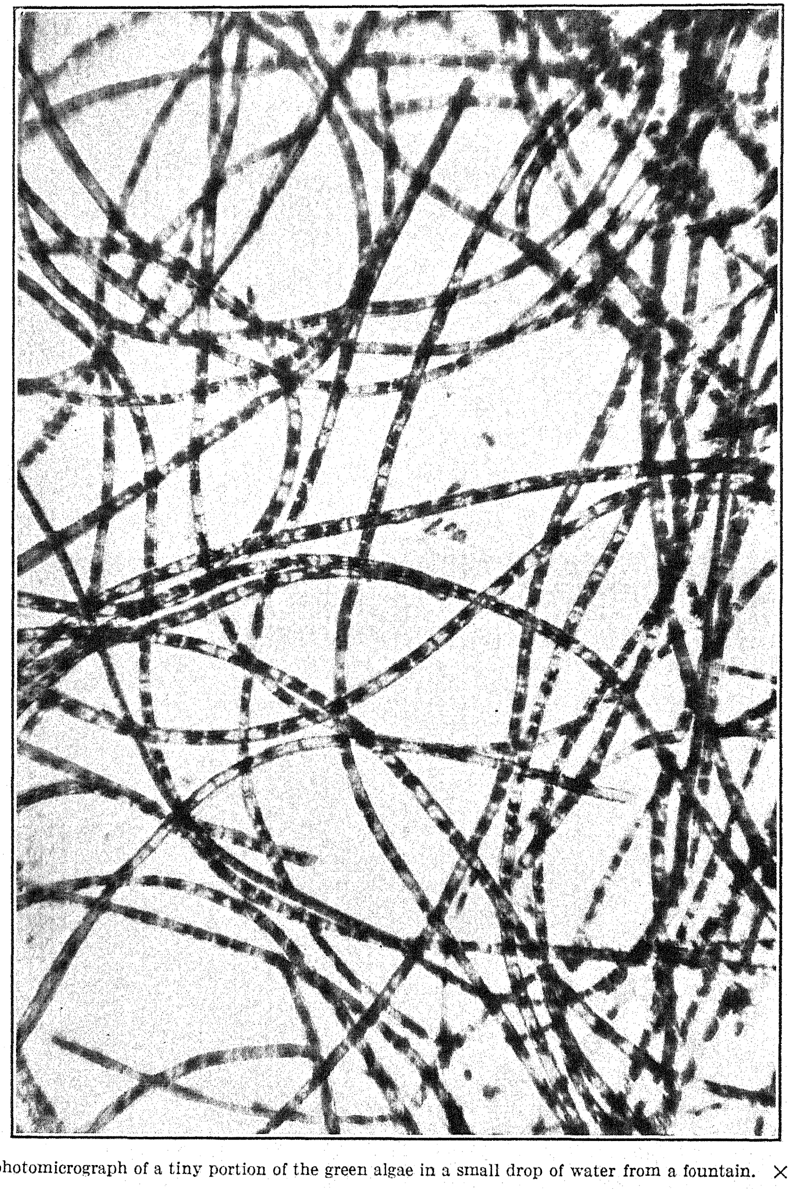
Courtesy of Dorothy Meier.

2. Visible and microscopic algae grow on the stones and in the waters of brooks in the spring and summer.

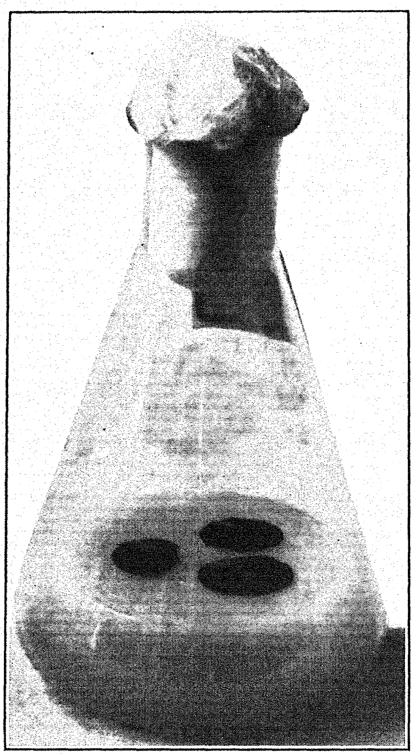


Courtesy New York Zoological Society.

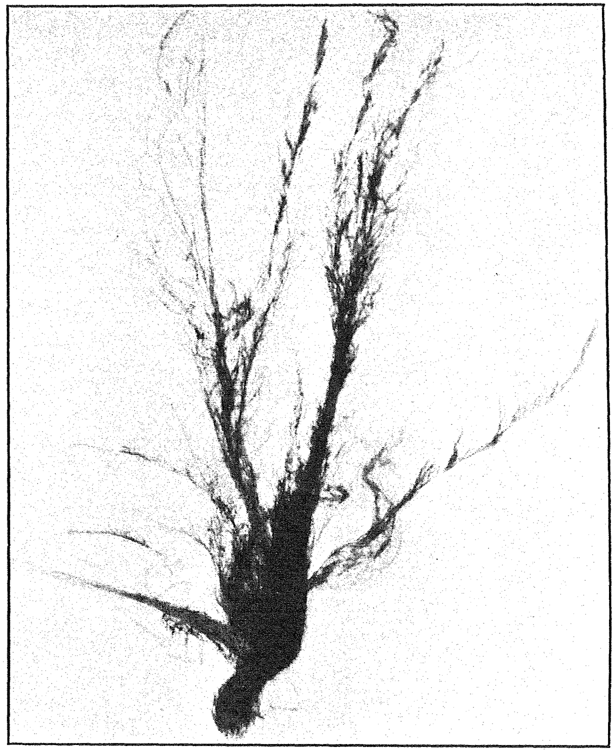
3. Microscopic algae growing on the hairs of the three-toed sloth make it bright green in color.



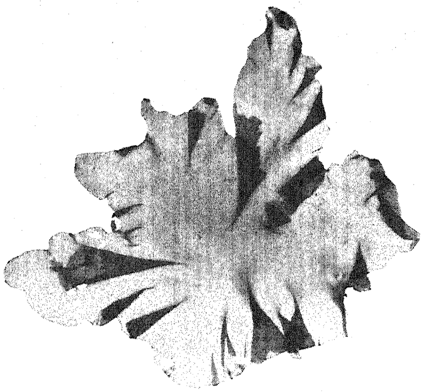
A photomicrograph of a tiny portion of the green algae in a small drop of water from a fountain. ×168.



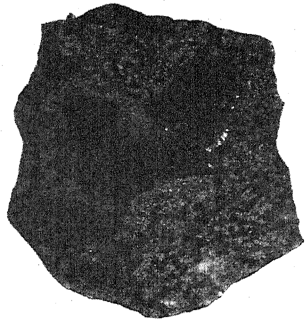
1. A pure culture of a unicellular green alga, *Scenedesmus quadricauda*, growing on nutrient agar suitable for scientific experiments relating to photosynthesis, radiation, growth-promoting substances, and nutrition of plants. $\times \frac{3}{4}$.



2. A green alga, *Cladophora kuetzingiana* Grunow, from Los Angeles, Calif. $\times$ Approximately $\frac{5}{7}$.



1



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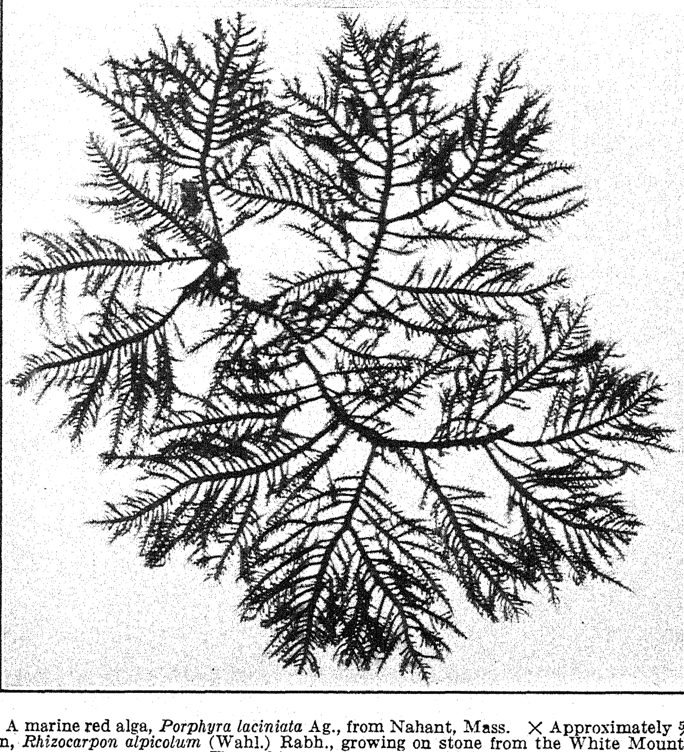
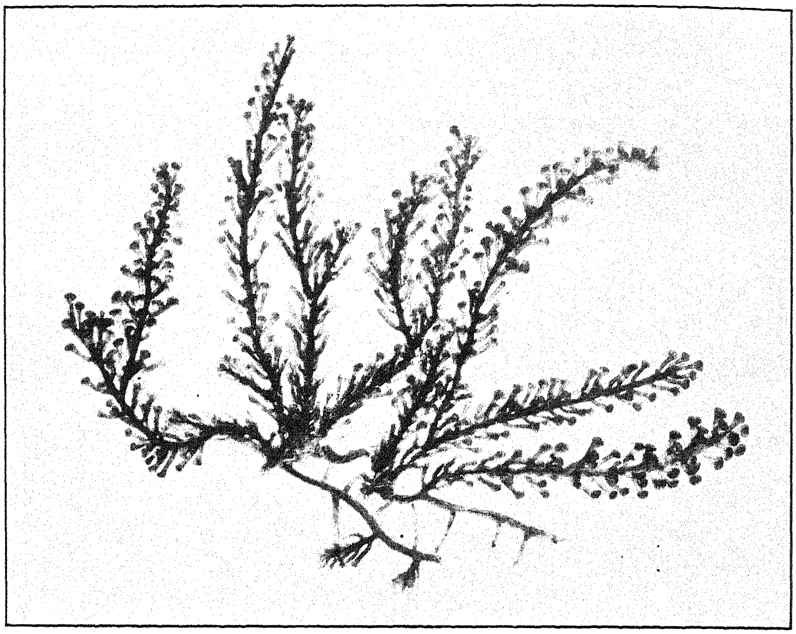
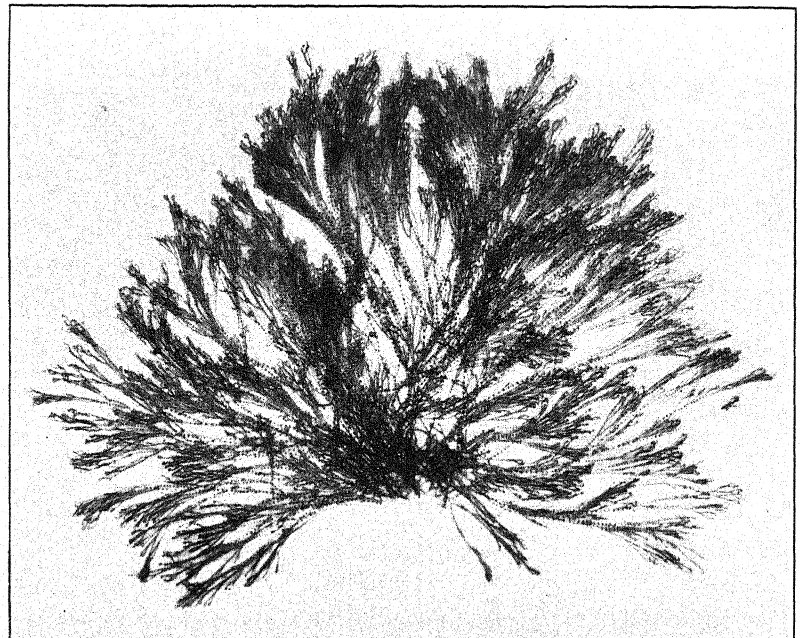


4

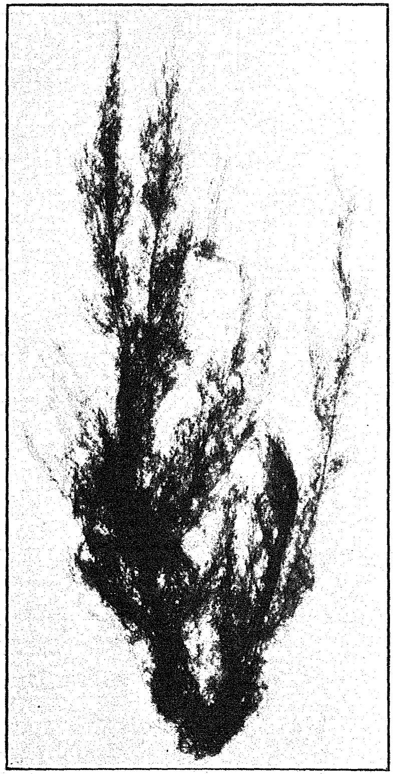
1. A marine red alga, *Porphyra laciniata* Ag., from Nahant, Mass. × Approximately 5/7.
2. A lichen, *Rhizocarpon alpicolum* (Wahl.) Rabh., growing on stone from the White Mountains, New Hampshire. × Approximately 5/7.
3. A lichen, *Rhizocarpon calcareum* (Weis.) Anzi, growing on stone from Labrador. Natural size.
4. A marine red alga, *Ptilota pectinata* (Gunn.) Kjellm., from the New England coast. Natural size.



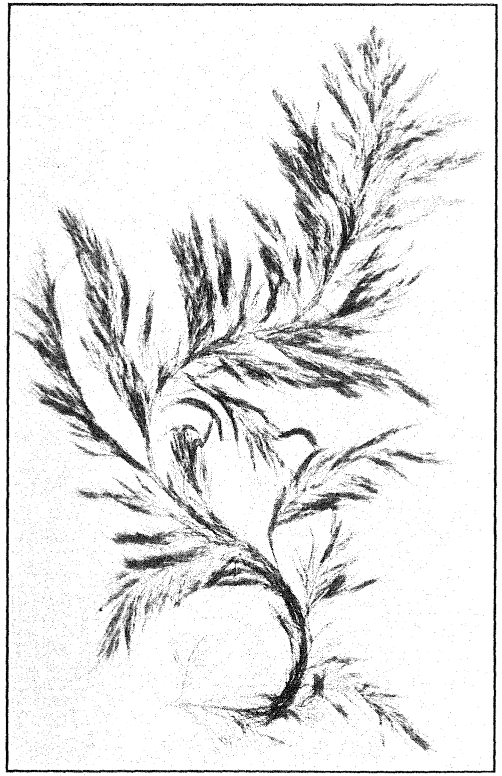
1. A marine green alga, *Caulerpa racemosa* var. *occidentalis* (J. Ag.) Børg., from Bermuda. × Approximately 3/4.



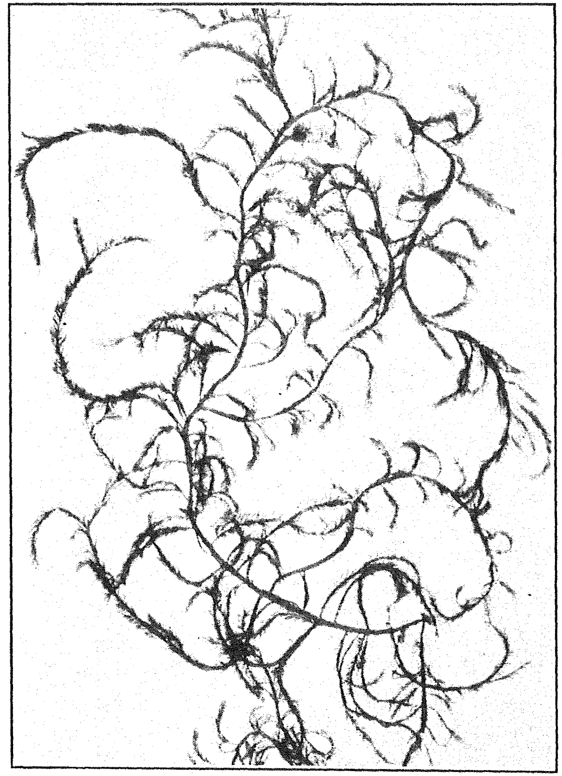
2. A marine red alga, *Ceramium ciliatum* (Ellis) Ducl., from the coast of England or Scotland. Natural size.



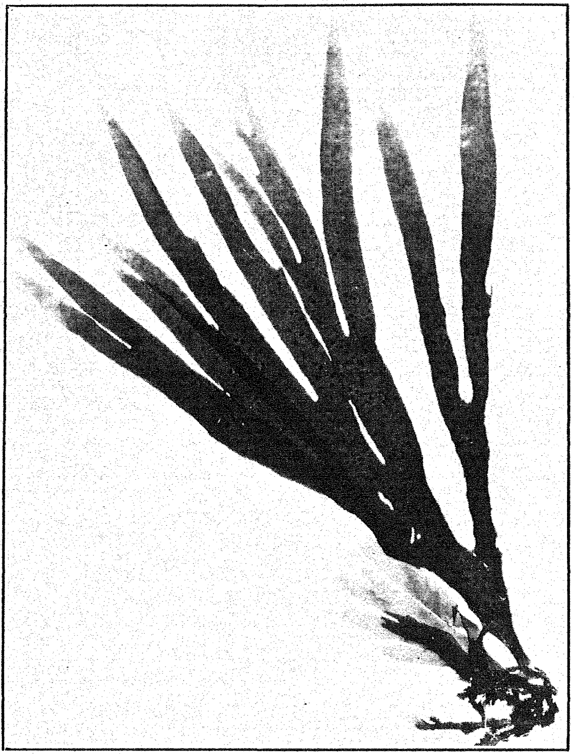
1. A marine red alga, *Antithamnion pacificum* (Harv.) Kylin, from San Juan Island, Washington. × Approximately ½.



2. A marine brown alga, *Desmarestia viridis* (Muell.) Lamour, from Newport, R. I. × Approximately 4/7.



3. A marine red alga, *Dasya pedicellata* (Ag.) Ag., from Rhode Island. × Approximately 5/6.



1. A marine red alga, *Callophyllis furcata* Farlow, from California. × Approximately 3/7.

2. A marine brown alga, *Sargassum filipendula* Ag., from Mauritius. × Approximately 3/7.

THE BOULDER CANYON PROJECT

By Wesley R. Nelson
Associate Engineer, Boulder Canyon Project

[With 10 plates]

From the year 1537, when the caravels of Francisco de Ulloa, a lieutenant of Cortez, attempted passage up the Colorado River from the Gulf of California only to be turned back by the river's bore, an unending battle has been waged to bring the Colorado under man's control.

Born in the melting snows of the Rockies of Colorado and Wyoming, and receiving sustenance from tributaries in southwestern States, the river has cut its way for millions of years through all the obstacles raised in its path to the sea. The mile-deep chasm of Grand Canyon, the sheer cuts through mountain ranges at Boulder and Black Canyons, and the delta thrown entirely across the Gulf of California, forming the Imperial Valley, attest the great power of this erosive agent.

For most of its 1,700-mile journey, the Colorado flows through lands that are incapable of producing crops, owing to insufficient rainfall in the growing season. Summer rains in the lowlands are in the nature of cloudbursts, and in many cases are a detriment rather than an aid, owing to the wearing away of the land. The river's flow is very erratic and difficult to forecast. Heavy rains may cause floods in any month of the year, but high water of 100,000 or 200,000 cubic feet per second flow usually occurs in the spring and early summer, and the river is at its low state of 3,000 to 4,000 cubic feet per second from September to February.

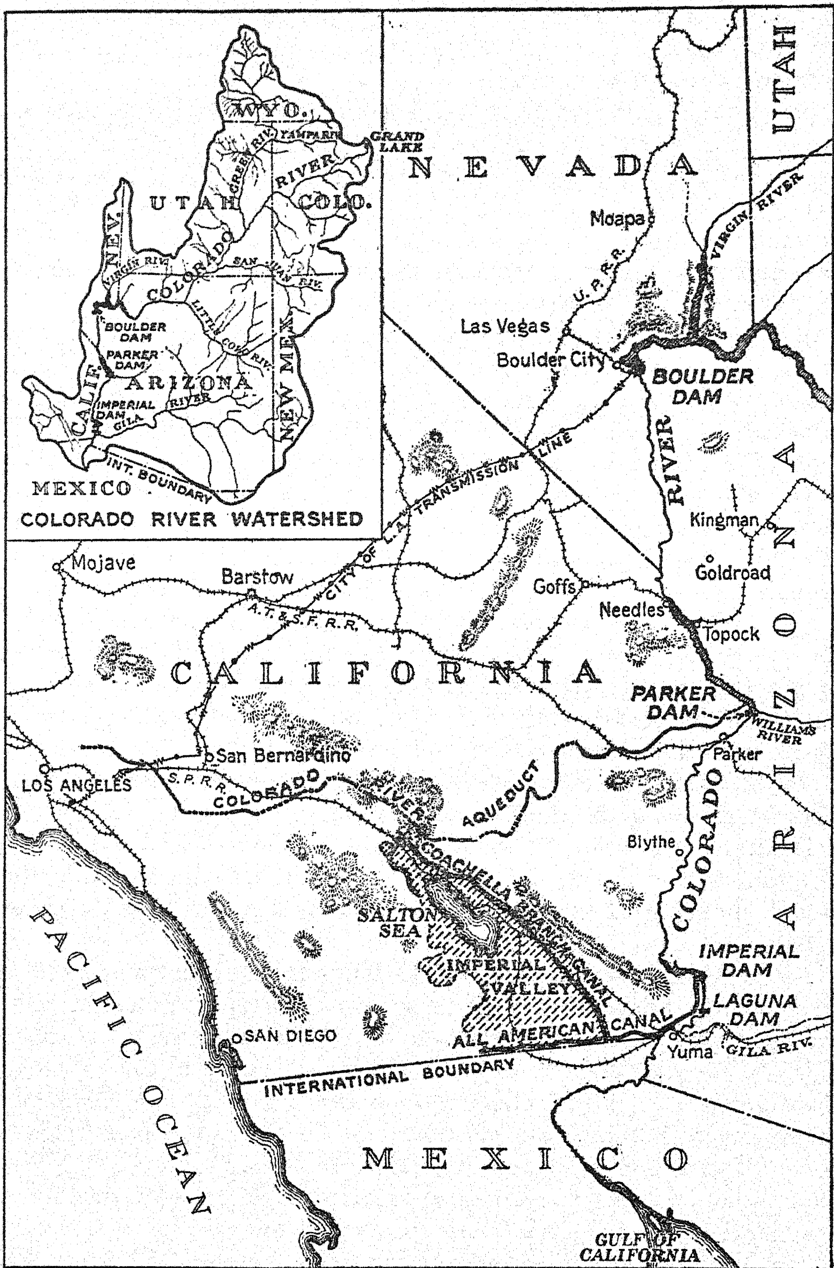
At first the river's conquest was considered in terms of navigation. History reports that Hernando de Alarcon in 1540 conquered the swift running waters at the mouth of the river, where the struggle between Gulf tide and river current defeated de Ulloa, and ascended the river a hundred miles upstream to the present location of Yuma, Ariz. In later years, frontiersmen in search of good hunting, gold, and homes sought to travel downstream on its waters and thus avoid the hazardous and laborious journey overland through cold mountain ranges, hot arid desert, or unfriendly Indian country. A few

succeeded, but many lost their boats and even their lives in the swift, treacherous rapids that are scattered the full length of the river wherever cloudbursts in side canyons have thrown rock barriers across the river channel. The members of the Church of the Latter Day Saints established homes and settlements in the Salt Lake Valley of Utah, and in their endeavor to build a southwestern empire sought an outlet to the Pacific Ocean down the Colorado. Their efforts met with some success, but these plans and others of similar nature were abandoned when the gap in the transcontinental railroad was closed at Ogden, Utah, in 1869, providing safe and rapid transportation to the East and West.

As the lands became settled along the Colorado and its tributaries, the waters were diverted into canals and used for the irrigation of crops. In the upper reaches, the irrigation projects were successful, but serious trouble soon developed in the irrigated lands of Arizona and California, particularly in the Imperial Valley, 150 miles south of Los Angeles.

Here in the basin cut off from the Gulf of California by the delta of the Colorado River was an ideal spot to grow many kinds of fruits, vegetables, and cereals, for the temperatures were nearly tropical, the growing season was 12 months in the year, a nearby market was furnished by the cities of Southern California, and water could easily be secured from the river channel on the silt delta 200 feet or more in elevation above the farms. Considerable trouble was caused by the silt deposition in ditches and canals, and the low flow of the river in the fall and winter months did not provide sufficient water for the rapidly growing demands of new farms. However, more and more land was placed under cultivation, and cities began to rise in the valley—when the Colorado struck again in characteristic fashion.

In the year 1905, an unprotected canal heading offered the opportunity, the river turned from its course, deep canyons were cut across fertile farms, railroads were destroyed, and inundation of the entire valley was started. Attempt after attempt to stop the flow failed as the river cut through the soft silt around obstacles placed in its path. The Southern Pacific Railroad took over the battle, rock was hauled by train loads and dumped into the gap, at times tracks, train, and load disappeared beneath the muddy waters, but finally, 18 months after the break, the struggle was won. The river was turned back into its original channel, and the inhabitants of the valley could once more resume their normal mode of life. The cost of the unfortunate episode ran into the millions and has never been accurately calculated, but a lesson was gained by the valley dwellers



GENERAL LOCATION OF BOULDER DAM, ALL AMERICAN CANAL, AND RELATED PROJECTS

FIGURE 1.

that stood them well in the following battles with the river, and the event focused attention of the State and Nation to the need for lower Colorado River control.

On several later occasions the river threatened to break through the dikes, and of the 150 miles of levees that have been built to hold the Colorado in its channel only one-third now remain. Thus the struggle with silt and flood has continued, while ever in the background has hovered the dread spectre of drought. Only a high dam and huge reservoir could successfully control the river, but the cost was too great to be borne by the lands directly benefited.

Aid, however, was not far away. Man has ever traveled westward in the settlement of our country, and in southern California, where the slopes of the Pacific are bathed in the warm winds of the Japanese current, he had found a land much to his liking. The large ranches and presidios of the Spaniards were transformed into smaller towns and farms. Towns grew to cities, and these, under the impetus of vigorous advertising and an aggressive community spirit, often doubled in population each year. Water for domestic use was brought by steel and concrete lines fom mountains hundreds of miles away, hydraulic and steam plants were built to supply the needs for power and light, until, finally, the continued growth required greater supplies of water and power. Here then lay the solution of the problems confronting both the Imperial Valley and southern California cities, for the Colorado River could be harnessed to supply water and electric energy, while the same curb would restrain the destructive forces of flood, silt, and drought.

Equitable allocation of the river waters between the States of the Colorado River Basin, the location of a suitable dam site, and the actual financing of the project construction were the next obstacles presented.

As mentioned before, most of the lands in the Southwest require irrigation for the raising of farm produce; consequently, the streams are its very life blood, and it was to be expected that the distribution of the Colorado River waters passing through several States would involve much dispute. The Colorado River Commission, composed of representatives of the seven States of the Colorado River Basin—Arizona, California, Nevada, New Mexico, Utah, Colorado, and Wyoming—was formed to discuss the matter. After several meetings, the State commissioners, with Secretary of Commerce Herbert Hoover as the United States representative, gathered in Santa Fe, N. Mex., in 1922, and there framed the Colorado River compact whose primary provisions were as follows:

1. Division, for reference, of the Colorado River Basin into the upper basin and lower basin, the dividing line being at Lee's Ferry a mile downstream from

the Paria River confluence. Thus the upper basin includes parts of Arizona, Colorado, New Mexico, and Utah, while the lower basin contains parts of Arizona, California, Nevada, New Mexico, and Utah.

2. Consumptive use of 7,500,000 acre-feet of water per annum was apportioned to each basin and, in addition, the lower basin was given the right to increase its consumptive use by 1,000,000 acre-feet per annum.

3. The upper basin States were not to deplete the run-off below an average of 75,000,000 acre-feet in 10 years, and the lower basin States were not to require the delivery of water which could not be reasonably used.

4. The use of the river for navigation should be subservient to the use of its waters for domestic, agricultural, and power purposes.

5. The compact should not be binding until it was approved by the Congress of the United States and by the legislatures of the seven basin States.

All State legislatures, excepting Arizona, later ratified the compact, but not before many years of disputes.

Investigations of the Colorado River for suitable dam sites, leading to the ultimate and complete development of the river's resources, have been in progress under the direction of the Department of the Interior through the Bureau of Reclamation since this Bureau was established by the Reclamation Act (ch. 1093, 32 Stat. 388) during the term of office of President Theodore Roosevelt. In the lower basin, the principal dam sites were early recognized to be at Black and Boulder Canyons. These two narrow gorges are located on the Arizona-Nevada boundary, Boulder Canyon being immediately downstream from the Virgin River confluence, and Black Canyon 20 miles farther downstream. Bright Angel Crossing in Grand Canyon is 270 miles upstream from Black Canyon, and the Gulf of California 450 miles downstream.

Geologic and topographic surveys were made of the two dam sites and their reservoir areas starting in 1919, and examinations of foundation conditions by diamond drilling were conducted at Boulder and Black Canyons from 1920 to 1923. Owing to the hazards in flood periods and the unbearable living conditions, where shade temperatures of 130° were often noted in the reflected heat from the canyon walls, drilling was done primarily in the fall and winter. Nevertheless, on more than one occasion drill barges were wrecked by sudden floods and drift wood, cloudbursts washed away the roads leading to the camps, and high winds leveled their tents.

Data obtained from investigations by the Bureau of Reclamation on the Colorado River were compiled in 1924 by Chief Engineer F. E. Weymouth and submitted to Secretary of Interior Hubert Work in eight volumes entitled "The Problems of the Colorado River." Preliminary plans and estimates were made of dam sites located at numerous positions along the river and particular emphasis given to a projected high dam at Boulder or Black Canyon. It is interesting to note that the preliminary estimate of $120,000,000

for this latter dam is now expected to be within 1 or 2 percent of the actual expenditure.

Congress was petitioned by Secretary Work to commence construction of the high dam, but several years of legislative disputes, both State and National, intervened before the Swing-Johnson bill became the Boulder Canyon Project Act (ch. 42, 45 Stat. 1057) and was signed by President Coolidge on December 21, 1928. Important qualifications in the act were:

1. The purposes of the construction were flood control, improvement of navigation, and storage and delivery of water for irrigation and domestic uses.
2. Appropriations were to be made not to exceed $165,000,000, of which amount $126,500,000 were allotted to the dam and power plant, and $38,500,000 for the All-American Canal to the Imperial Valley.
3. No appropriations were to be made until contracts for power were signed, providing for repayment within 50 years of all charges, and interest, for construction of the dam and power plant.
4. Expenditures for building the All-American Canal were to be repaid by the landowners on a prorated basis of the acres of land receiving water.
5. All of the seven States of the Colorado River Basin were required to ratify the Colorado River compact, or, if this were not done in 6 months, the compact was to be ratified by California and five other States, before construction could proceed.
6. California was to agree that the use of water in that State from the Colorado River should not exceed 4,400,000 acre-feet, plus not more than one-half of any excess water unapportioned by the compact.

Conferences were called by Secretary of Interior Ray Lyman Wilbur with all parties interested in obtaining electric power from the power plant, and as a result, contracts were signed with the city of Los Angeles, Southern California Edison Co., and the Metropolitan Water District of Southern California, whereby all construction charges, and interest, would be repaid within a period of 50 years after the first power was generated. Allocations of firm power were:

	Percent
State of Arizona	18
State of Nevada	18
Metropolitan Water District	36
Smaller municipalities	6
City of Los Angeles	13
Southern California Edison Co	9

All secondary energy was allocated to the Metropolitan Water District. Firm power available throughout the year was to be sold to the contractors at generator voltage for $0.00163 per kilowatt-hour and secondary power, available when reservoir conditions permitted, at $0.0005 per kilowatt-hour.

All State legislatures, except Arizona, ratified the Colorado River compact, and on July 3, 1930, President Hoover signed the second

deficiency bill, making $10,660,000 available for commencing construction of a dam at Boulder or Black Canyon. A board of consulting engineers reviewed the attributes of the two sites and agreed with the engineers of the Bureau of Reclamation that the location in Black Canyon should be adopted. The principal reasons for placing the dam there were that geologic conditions were better, the depth to bedrock was less, and a dam of smaller dimensions would provide the same reservoir capacity. Furthermore, the distance to power markets was not so great, and transportation facilities to the project could be provided at less cost.

Fundamentally, the problem presented to the engineer in order to gain control of the Colorado was the placing of a high barrier across the stream which would create a storage basin of sufficient magnitude to stop the river floods, store the spring run-off for all-year utilization, and provide a huge silt pocket. This latter feature was required to be of a type that would not interfere with the production of power or destroy the efficiency of the reservoir. The power plant was also required to be constructed of a capacity adequate to pay all costs of construction from the sales of electrical energy produced by the generators.

After much study, it was determined that these requirements could be most successfully and efficiently fulfilled by building the dam to store 30,500,000 acre-feet of water and erecting a powerhouse immediately downstream of 1,835,000-horsepower capacity. Protection of the dam and powerhouse from reservoir overflow would be provided by two spillways, whose outlets would be through tunnels around the dam, and normal regulation of the reservoir and the furnishing of water to the powerhouse turbines would be secured by four penstock and outlet systems. Each of these latter systems would consist of an intake tower equipped with two gates and located in the reservoir immediately upstream from the dam, and a system of steel pipes in tunnels leading from the tower base to the power plant or past the powerhouse to needle valves in outlet works.

Building a dam in Black Canyon offered so many obstacles that many claimed the project was not feasible, and that, in fact, its construction could not be accomplished. A few of their arguments were that the geologic conditions at the canyon were not right for so large a dam; transportation across deserts and down 800 feet into the canyon was too difficult for the moving of millions of tons of materials that must be placed in construction; the site was in the middle of the desert where men could not work in summer, owing to the extreme heat; no contracting company would risk bidding on so large a job where building conditions were so difficult; the river could not be controlled while the dam was being built; a dam of the size pro-

posed had never been built, and its great magnitude presented problems which could not be solved; and the river silt would fill the reservoir in a short time or would destroy the gates, valves, and turbines if allowed to pass through them.

Geologic examinations, channel drilling and tunneling into the dam abutment during the preliminary investigations had shown the rock to be satisfactory, and the later excavations for construction verified this conclusion. In the following paragraphs, descriptions will be given of the manner in which other questions were answered.

Primarily on account of its inherent safety features, the dam selected to be built in Black Canyon was one of arch gravity type in which the thrust of the water is taken first by its weight (6,500,000 tons) and, secondly, by the arching action upstream. To provide the necessary reservoir storage with this type of structure, the required dam would have a height of 726 feet (nearly that of the Woolworth Building in New York); a base thickness of 660 feet (more than the length of two ordinary residence blocks); a crest whose thickness is 45 feet and length 1,282 feet—on which a highway has been constructed; and contain 3,250,000 cubic yards of concrete (a greater volume than that of the largest Egyptian pyramid).

Owing to the large dimensions of the dam and the enormous volume of concrete to be placed, the problem of temperature stresses within the concrete became one of great importance, and much research and study were conducted by Bureau of Reclamation engineers before a practical solution was reached. Concrete would be poured in the dam during the summertime at a temperature above 100° F. and another approximately 40° F. would be added by the chemical heat of setting. If allowed to cool by natural means, the temperature of the dam would not be lowered to that of the air and water surrounding it for a period of as much as 150 years. During this time, cracking would occur due to contraction of the concrete.

The dam was, therefore, designed and built as a group of 230 interlocking vertical columns varying in size from 25 to 60 feet square. Steel tubing of 1 inch diameter was installed in the concrete at approximately 5-foot intervals, both vertically and horizontally, and water at a temperature as low as 30° F. circulated through the concrete of the dam. Thus the entire mass of the dam was cooled to predetermined temperatures ranging from 43° to 72° F. in a period of 19 months.

As planned, the contraction of the concrete due to cooling caused the columns to separate. These openings were filled with a water-cement grout as soon as cooling was finished. Consequently, as the

concrete expanded, due to its increase in temperature to that of the surrounding medium, the concrete was placed in compression and the possibility of future cracking eliminated. Cooling tubing placed in the dam amounted to 582 miles and grouting pipe 180 miles.

How effectively the system of cooling and grouting has worked can best be seen by an examination from one of the numerous inspection galleries that cross the dam on horizontal and circumferential lines. One of these, the abutment gallery, starts in the dam near the top of an abutment, follows it downward, crosses the river channel within 5 to 30 feet of foundation rock and ascends along the other abutment to the dam crest. Other galleries pierce the dam in circumferential and radial lines at levels 12, 257, 357, 452, 527, and 558 feet below the crest. All, except the lower of the circumferential galleries, contact the two elevator shafts which connect with the dam crest.

Water that otherwise would percolate past the dam through small crevices and fissures in the rock was halted by injecting water-cement grout into the foundations and abutments. Holes for grouting were drilled into the rock at 5-foot intervals the full height of each abutment and across the base, to a depth as great as 150 feet, and grout forced into the rock at pressures as high as 1,000 pounds per square inch. Any water passing the grout curtain will be caught by drainage holes drilled at 10-foot centers from the abutment gallery downstream from the curtain. Drainage from the gallery is provided by a passage through the dam to its downstream face.

The reservoir formed by this high dam will be the largest man-made lake. When filled to capacity, it will contain sufficient water to cover the State of Connecticut 10 feet deep, its shore line will extend 550 miles, and its depth at the dam will be 589 feet. If the entire flow of the river were stopped, the lake would fill in 2 years of mean flow, but owing to the demands for downstream irrigation, at least 3 years will be required. The 30,500,000 acre-foot capacity of the reservoir is allocated to the following uses: The lower 5,000,000 to 8,000,000 acre-feet for a silt pocket, the next 12,000,000 to 15,000,000 for active storage, and the upper 9,500,000 for flood control.

The two spillways, which take the overflow of the reservoir, are located upstream and off to the sides of the dam. Each spillway channel has a length greater than that of two residence blocks, is a half block wide and a hundred feet deep. A concrete weir, whose unobstructed crest length is 400 feet, forms the upstream part of the channel on its reservoir side, and the downstream end of the channel is connected with the river below the powerhouse by a shaft, which drops downward on an incline a vertical height of 500

feet, and an "outer diversion tunnel" that has been driven through the cliffs past the dam. The largest battleship could be floated in the channel if the inclined shaft were damned at the portal. It is also of interest to note that if the spillways were operating at their capacity of twice the highest river discharge ever recorded at Black Canyon, the water would pass into the outer diversion tunnel at a velocity of 2 miles per minute while the energy expended would exceed 11,000,000 horsepower. However, a discharge of this volume will never occur, except in the most extreme emergency, for floods equal to the severest ever experienced on the river can be restrained by the outlet works and spillway gates to a flow past the dam of not more than 75,000 cubic feet per second, or approximately one-fifth of the spillway capacity.

Four structural steel floating gates, a hundred feet in length and of circular segment section, are installed on each weir. Ordinarily the gates lie in recesses in the weirs, but, as the reservoir rises, they may be lifted as much as 16 feet to regulate the flow into the spillway channel. Each gate is hinged on the reservoir side and, although weighing 500,000 pounds, it is a buoyant vessel and can be raised by allowing water to enter the weir recess and float the gate to the desired height. It may be lowered, conversely, by allowing the water to flow from the recess into the spillway inclined shaft. With gates in lowered position, the weir crest is 27 feet below the dam crest.

Water will be taken from the reservoir for downstream requirements, production of electricity, and regulation of the reservoir surface below the weir crests of the spillways, through the gates located in the four intake towers, the steel pipes in the penstock and outlet systems, and the needle valves of outlet works, or the turbines of the power plant.

The four intake towers that are located just upstream from the dam are notable examples of the possibilities presented for combining artistry and usefulness, of building for beauty as well as for strength and utility. These graceful concrete spires resemble huge fluted columns and have all the appearance of memorial monuments rather than serviceable structures designed for the particular purpose of regulating the flow of water from the Boulder Canyon Reservoir.

Actually each tower is a hollow concrete cylinder of 29 feet 8 inches internal diameter and 75 feet average outside diameter from which 12 fins project radially, the openings between the fins being spanned by steel trash racks. A hoist house of more than four stories high sits atop each tower and contains electrically operated hoists for raising and lowering the cylindrical gates that are installed,

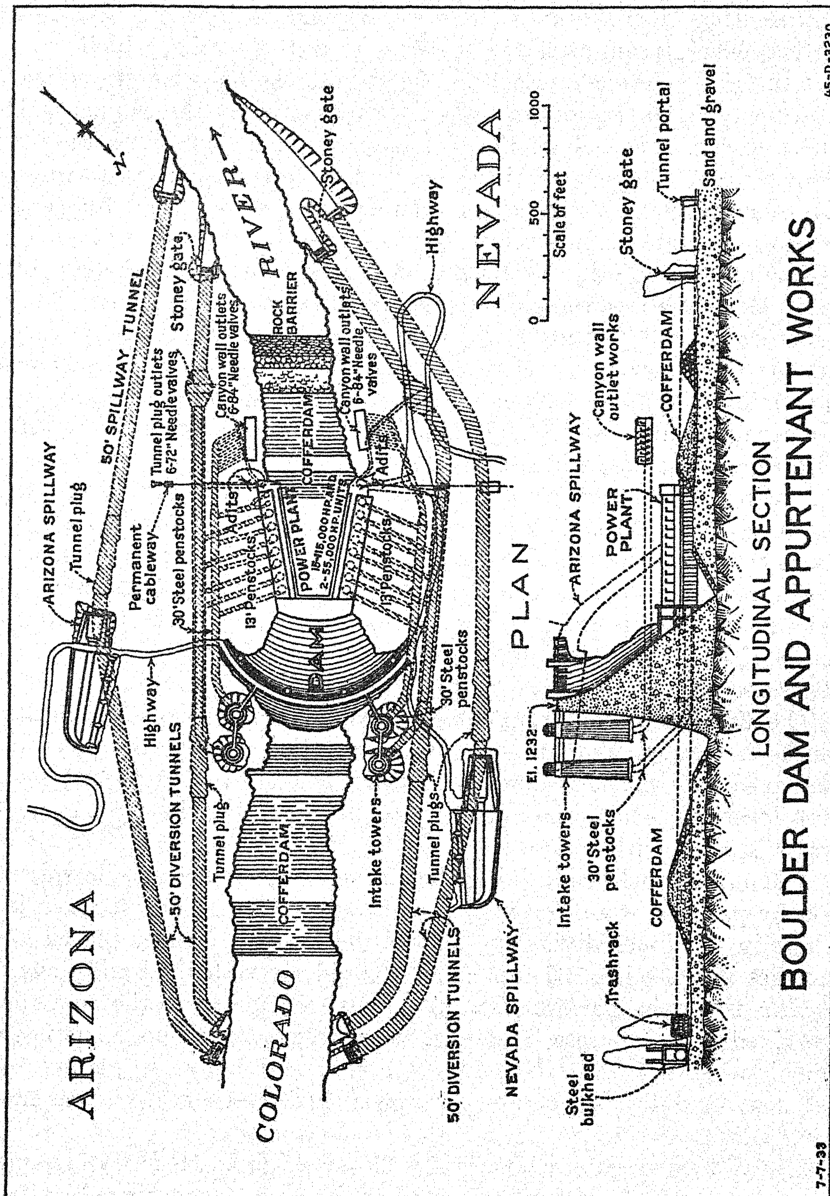


FIGURE 2.

one at the tower base and another 150 feet higher. The over-all height of each tower is 403 feet above its rock foundation, equal to that of a 34-story building.

Water from the reservoir will enter the tower through the steel passage liners and gate opening (the gate being in raised position) to a 30-foot diameter steel pipe line that connects with the tower base.

It then flows downstream to the power-plant turbines or continues farther downstream past the turbines to outlet works, which open into the river channel. Each of the two downstream towers is connected with a battery of six 84-inch needle valves in the canyon wall outlet works, and each of the two upstream structures with the six 72-inch needle valves contained in the downstream plug of an inner diversion tunnel. Connections between the 30-foot pipe line and the power-plant turbines are through 13-foot diameter steel pipes.

Foundations for the towers are on rock shelves cut in the canyon walls 250 feet above the old river surface, and the high points of the structures rise 56 feet above the dam crest. Two towers are on each side of the canyon, the center line of the downstream ones being approximately 135 feet from the dam face and the other two 185 feet farther upstream. Bridges join the upstream and downstream towers with each other and with the dam.

Placing the tower foundations so far above the old river bed produces a silt pocket, and thus clear water can be supplied at all times to the powerhouse turbines or outlet works. Silt deposition in the reservoir will be heavy, but will be relieved by upstream development, and present indications are that not more than one-tenth of the reservoir volume will be filled with silt at the end of 50 years.

The flow of water from intake towers to powerhouse or outlet works is carried in plate steel pipes installed on concrete piers in the lined tunnels. Anchors and thrust blocks are provided at several locations where the entire space between the pipe and tunnel walls is filled with concrete.

The outlet works containing the 72-inch and 84-inch needle valves for by-passing water around powerhouse turbines are located in plugs in the inner diversion tunnels and in valve houses placed on benches in the cliffs 160 feet above the old river channel and downstream from the powerhouse. A means of passage to the plugs is provided by a concrete lined adit whose canyon wall portal is near the downstream end of the powerhouse, and access is gained to the canyon wall valve houses through a shaft and elevator from the plug adit.

A steel Stoney gate, whose leaf is 35 feet high by 52 feet wide and 6 feet maximum thickness, is located at the downstream portal of the inner diversion tunnel to cut off the inflow from the river, whenever the requirement for maintenance work make such procedure desirable. The gate, weighing 260,000 pounds, is counter-weighted and is raised and lowered by two electrically operated hoists.

Immediately downstream from the dam lies the huge concrete and steel structure of the powerhouse. This is a U-shaped building

whose two wings nestle close to the cliffs, and the central section connecting them lies on the downstream face of the dam. The length around the U next to the cliffs and dam is nearly that of six ordinary residence blocks and the average width of each wing or central section approximately a half block. The height from lowest concrete to top of highest parapet is that of a 20-story building, and the parapet rises the height of 12 stories above low water surface in the tail race. The roof covers an area of 4 acres, is 4½ feet thick (to resist rock falling from the cliff above) and is composed of seven laminations, two of these being reinforced concrete, another asphalt paving, and others of sand and gravel. Support for the roof is provided primarily by 11,600,000 pounds of structural steel trusses and beams, and beneath the roof are 10 acres of floors.

When finally completed the power plant will contain fifteen 115,000-horsepower units, and two of 55,000, a total installed capacity of 1,835,000 horsepower. Included in the machinery that will be placed in the plant are 14-foot diameter butterfly valves, 40-foot diameter turbine scroll cases, 82,500 kilovolt-ampere generators, 55,000 kilovolt-ampere power transformers for raising the generator voltage from 16,500 to transmission voltage of 287,500, and 300-ton cranes. All units in the plant may be controlled from a single station or each unit may be run from a control board near it. Operating at rated capacity, the power plant would be capable of producing sufficient electric energy to supply complete domestic light and power for all the 8,500,000 inhabitants of the Colorado River Basin, or, calculated in a different manner, it would be enough to furnish each and every family in the United States with light from a 40-watt bulb.

Approach to the powerhouse is first by way of two elevators, which descend from the dam crest the height of a 44-story building, and then by passageways through the dam a block in length to the central section. Another route is by a mile and a half of road and a 1,900-foot tunnel which connect the Boulder City highway with the downstream end of the Nevada powerhouse wing.

A high-tension switchyard, at the ends of the transmission lines, is located a thousand feet from the Nevada canyon rim opposite the central section of the power house. Remote control from the power plant, of the oil circuit breakers located at the switchyard, is provided by electric circuits running from the central section upward through the cliff in an inclined shaft and thence continuing to the switchyard in a 6- by 8-foot concrete conduit.

Diversion of the Colorado River while the dam and power plant were being constructed presented a difficult problem owing to the narrowness of the canyon, the extent in and up-and-down-stream

direction of the canyon workings, and the possible large fluctuations of the river's flow.

A final decision was made to drive two diversion tunnels through each canyon wall around the dam and powerhouse site, erect an earthfill cofferdam downstream from the inlet portals and another upstream from the outlet portals, place steel bulkhead gates at the inlet portals of the two tunnels farther from the river (termed the "outer diversion tunnels"), build plugs in the two tunnels closer to the river (termed the "inner diversion tunnels"), and construct plugs in the outer diversion tunnels—the one on the Nevada side to contain high pressure slide gates for temporary use during the filling of the lower portion of the reservoir.

The downstream two-thirds of the diversion tunnels were to be used later in the operation of the reservoir, the outer ones becoming the outlets for the spillways and the inner ones containing the penstock headers from the upstream intake towers. Plugs were, therefore, placed in the diversion tunnels immediately upstream from the intersections with the inclined tunnels to the spillways and to the towers. As previously mentioned, the inner diversion tunnels also contained plugs for outlet works at the downstream ends of the pipe headers.

Control of the river consisted in turning it through the diversion tunnels by means of temporary dikes, building the cofferdams behind these protecting dams, shutting off the flow through the inner diversion tunnels and the outer Nevada diversion tunnel in periods of low river flow while temporary dams were dumped across the tunnel inlets and outlets, and constructing concrete plugs in these three tunnels, the outer Nevada one being equipped with gates. The bulkhead at the inlet of the outer Arizona tunnel was lowered, diverting the river flow through the outer Nevada tunnel under control of the slide gates, thus commencing storage in the reservoir. A concrete plug was then built in the Arizona outer tunnel.

After the reservoir has risen to the lower gates in the intake towers, and one of the outlet systems is ready for operation, the river control will be taken over by the needle valves in the outlet works. The bulkhead at the inlet of the Nevada outer tunnel will be lowered by remote control, as the gate sill will be under at least 265 feet of water, and the slide gates in the plug closed for the last time. The openings through the plug will then be filled with concrete and grouted.

Each of the four diversion tunnels was excavated to 56-foot diameter—as high as a 4-story building—and lined with a 3-foot thickness of concrete. The total length of the tunnels was approximately 3 miles. Plugs placed in diversion tunnels, immediately

up-stream from the intersections with the inclines to spillways and intake towers, were 200 feet to 393 feet in length; and the gates for temporary diversion in the Nevada outer tunnel consisted of four sets of 6½-foot by 7-foot slide gates, operated by motor-driven oil pumps and hydraulic cylinders. Bulkhead gates placed at the inlets of diversion tunnels were built of structural steel plates and members, making a section approximately 56 feet wide, 51 feet high, and 12½ feet thick. Two hydraulic cylinders, nearly 8 feet in diameter and 70 feet in height, were required to lower or raise each gate in its steel and concrete frame, water being released from the cylinders in the lowering operations or being pumped beneath the piston heads to raise the gate. Forty-two railroad cars were required to bring one gate to the project, the weight of the moving parts of each gate being in excess of 2,000,000 pounds, and its frame, cylinder, and other operating parts another million pounds.

The cofferdams themselves were larger than many diversion dams located along the tributaries of the Colorado and were constructed with greater care than numerous more permanent structures. Essentially they were rolled earth fills whose slopes away from the river were covered with heavy rock blankets. A 4-inch thickness of reinforced concrete covered the upstream face of the upper cofferdam, sheet steel piling extended to rock across the upstream toe, and a rubber seal at the intersections of the face paving with the canyon walls and sheet piling prevented percolation of water through these vulnerable locations. A massive barrier of rock was placed immediately downstream from the lower cofferdam to protect it from eddy action of the river upon its exit from the diversion tunnels. After serving their purpose of diverting the river, the lower cofferdam and rock barrier were removed as otherwise they would obstruct the flow from the powerhouse tailrace.

The upper cofferdam was 480 feet long, 750 feet thick at the base, and 98 feet high; the lower cofferdam 350 feet long, 550 feet thick at the base, and 66 feet high, while the rock barrier was 375 feet long, 200 feet thick at the base and 54 feet high. The crest width of the upper cofferdam was 70 feet and of each of the downstream structures 50 feet. Materials placed in the dams amounted to 514,616 cubic yards of earth, 108,156 cubic yards of rock, and 2,394 cubic yards of concrete.

Following the skirmishes with the river in the Imperial Valley and the preliminary engagements of a financial, legislative, and preparatory nature came the eventual conflict with the Colorado at Black Canyon—the supreme test of man's ingenuity when finally engaged in battle with nature's forces. Arrayed on the river's side were not only cloudbursts, silt, and sudden floods, but as well the

severe desert climate, the three-dimensional obstacle of transportation to the canyon and down 800 feet to the canyon floor, and the difficulties of working in and on the sheer walls. Allied with men were the knowledge gained from winning many similar battles, an ideal site for the huge dam, and directly at hand the development and use of modern machinery.

Work was started in Black Canyon the day after the first appropriation was made available. Surveys were conducted by aerial and ground photography and later supplemented by detailed surveys of the canyon walls, in which latter work transits necessarily were set at hazardous points along the cliff, and the rodmen were lowered by ropes from canyon rims—at times swinging inward pendulum fashion to secure shots under overhangs, while a sheer drop of 500 feet lay below.

Specifications and drawings were being prepared in the Denver Office of the Bureau of Reclamation, in anticipation of the award of the principal labor contract in the fall of 1931. However, unemployment conditions were becoming stringent, and word came from Washington to rush the work to the greatest extent in order to assist in relieving the situation. Drafting forces were increased, designers worked night and day, and by Herculean efforts the major contract for construction of the dam, power plant, and appurtenant works was awarded to the lowest bidder (Six Companies, Inc.) on March 11, 1931, 6 months ahead of the date originally set. This was the largest labor contract ever awarded by the United States Government, the bid amounting to $48,890,995.50. Six Companies, Inc., is composed of six West coast contracting firms, who pooled their assets for the particular work at Black Canyon.

Care of the workers presented problems requiring earnest thought. Shade temperatures in Black Canyon rise to 130° F., the daily mean rests for weeks above 100°, metal left in the sun burns to the touch, and the black walls of the canyon throw off furnace-like waves of heat. After studying climatic and soil conditions, a location was chosen on a ridge 7 miles from the dam site where the beautiful little town of Boulder City is now situated. Here are clean paved streets, grass and shrubbery to break the sun's reflected glare, and homes, dormitories, and offices built to give maximum comfort in the summer heat. Water from the muddy Colorado is desilted, pumped 2,000 feet in elevation, softened and sterilized by chemicals and supplied through an efficient distribution system to Boulder City dwellers as a clear sparkling liquid. Electricity, brought 222 miles across desert and mountains, from California for construction power, also supplies the town with light and power. In the fall of 1931, the site of Boulder City was raw desert waste, but a year later

nearly a thousand dwellings comfortably housed the town's 5,000 persons.

Highways and railroads were built from main lines across 30 miles of desert to canyon rims. Other roads were constructed and rails laid to the bottom of Black Canyon and to various construction plants. Boats and barges first carried men and equipment on the river, but these were replaced early in construction by steel bridges and a group of cableways. Materials were required in quantities never before shipped to a single construction job in such a short time—5,000,000 barrels of cement; 8,000,000 tons of sand, gravel, and cobbles; 45,000,000 pounds of reinforcement steel; 18,000,000 pounds of structural steel; 21,000,000 pounds of gates and valves; and 840 miles of pipe were hauled over the railroads in the first 4 years of construction. On many days 60 cars of materials arrived on the project, and the total number of cars received in Boulder City from plants throughout the Nation amounted to more than 30,000, which figure does not include the 145,000 cars of sand, gravel, and cobbles placed in concrete construction.

Even as the structures at Black Canyon were required to be the greatest of their kind ever built, so were many of the plants and much of the equipment used in construction, the largest of their type. Trucks were provided with aluminum bodies, capable of hauling 16 cubic yards of materials, others were of 50-ton capacity, and some were converted into 100- and 150-man transports. Air compressor plants of 14,500 cubic feet per minute capacity were built near the river's edge. A 20-mile railroad, whose rolling stock included 29 steam and electric locomotives, was laid to connect all construction plants on the project.

Transportation of men and materials between canyon walls or from rim to river channel was accomplished in great part by the use of cableways. The first of these were small 8-ton installations whose track cables were fastened in concrete-filled tunnels in the canyon walls, but the five that were used primarily for placing concrete in the major features of construction were of 25-ton nominal capacity and of movable end tower type. Both of the end structures, or towers, of four of these and the tail tower of the fifth, to which the track cables were fastened, consisted of heavy structural steel frame works mounted on rails. The head and tail towers of the two largest cableways, whose spans were nearly a half mile, were 90 feet in height and the distances between center lines of front and rear tracks for each tower were 46 feet. The overturning moment from the cable and its load was counteracted primarily by a million-pound block of concrete placed over the rear tracks and by centrally located trucks which traveled against a rail

set with its web horizontal. The hoisting equipment was placed in the head towers on the Nevada side, and directions for movement of the load on the cableway were phoned to the operator by signalmen located at the loading and unloading sites. Winches in the head towers of each cableway for moving the towers on their tracks were electrically operated from the same circuit.

Perhaps the most important equipment of the contractor, Six Companies, Inc., was the sand and gravel screening and washing plant and the two concrete mixing plants. Pit material was hauled by rail to the screening plant and there separated into sand, cobbles, and three sizes of gravel. In its 34 months of operation, the plant classified 7,700,000 tons of concrete aggregates, and on many occasions processed 800 tons in 1 hour.

The Lo-Mix concrete plant was located 4,000 feet upstream from the dam and at the crest elevation of the upper cofferdam. Concrete produced by this plant amounted to 2,097,000 cubic yards. Its record for 1 day was 7,013 cubic yards and 182,784 in 1 month. The Hi-Mix plant was situated near the Nevada canyon rim, 650 feet downstream from the dam abutment. Placed in operation on March 1, 1933, this plant had mixed 2,324,000 cubic yards of concrete by October 1, 1935. As many as six 4-cubic-yard mixers were manufacturing concrete simultaneously, and on December 27, 1934, the plant produced 3,000 cubic yards in one 8-hour shift. Records established by both plants were 10,417 cubic yards in 1 day and 261,847 yards in 1 month. Cement was brought to the project in bulk, as many as 35 cars being used in 1 day. After July 7, 1933, all cement passed through a blending plant in order to blend the products from the various mills.

Excavation of the tunnels to carry the entire river flow while the dam and powerhouse were built was the first work undertaken at the dam site. The speed and dispatch with which the tunnels were driven by the contractor forecast the efficient and expeditious manner in which the entire construction program was to be completed. The canyon walls were first pierced with small bores along the tunnel line with the usual mining equipment of compressed-air drills, electric locomotives, and dump cars, but tunneling history was made in the enlargements to the full 56-foot circular section. An especially designed drilling jumbo, mounted on a truck and equipped with 30 drills, was backed up to the face, and a deafening roar filled the tunnel as the numerous drills ate their way 10, 15, 20 feet into solid rock. A ton of dynamite was loaded into the drill holes, all of the machinery moved away from the heading, and the following electrically fired blast shook the canyon walls. Power shovels moved to the tunnel face, the broken rock was loaded into trucks, and soon

these were filing in a long procession up steep grades to dump grounds in side canyons.

An average blasting round broke 1,000 cubic yards of rock and advanced the heading 17 feet. Work progressed at times from eight headings. A total length of 256 feet of tunnels was driven in 24 hours, and 6,848 feet in 1 month. Removal of the million and a half yards of rock in the 4 tunnels required 3,561,000 pounds of powder, or 2.38 pounds per cubic yard.

Lining the tunnels with concrete to prevent rock falls and furnish a smooth surface for water flow, thus increasing their capacity, was accomplished in the same capable way as were the excavations. Steel forms were used, those for the side walls weighing 250 tons for an 80-foot length. Concrete was placed behind them from spout dump buckets, through chutes, or forced into place by compressed air guns.

As soon as the two tunnels on the Arizona side were lined, the river was turned from its ages-old channel and detoured through the canyon walls for nearly a mile. The manner of its diversion is one of interest. A pile trestle bridge was first built across the river downstream from the diversion tunnel inlets, and the temporary dams in front of the Arizona tunnel portals were blasted. Trucks commenced dumping large rocks, then smaller ones, and finally silty sand from the bridge into the channel, thus forming a dam in 24 hours which entirely turned the river flow. A dike of tunnel muck was pushed across the river channel in the relatively still waters upstream from the tunnel outlets, and the area between the two temporary dams was then pumped dry.

Behind the protecting barriers of the two temporary dams, construction proceeded for the cofferdams, and excavations for the main structure of the dam and the powerhouse. Earth for the permanent cofferdams was secured principally from two pits in Hemenway Wash, 4 miles from the dam site, and was hauled by train to an interchange dump near the upper portals of the Nevada diversion tunnels. Shovels loaded the material from the dump into trucks which placed it in the dam. The earth was spread by caterpillar tractors, moistened by hose, and then compacted by a sheep's foot roller. Trains returning to the Hemenway pits were loaded with rock and channel muck from the canyon workings, this material being dumped at a suitable site 3 miles from the dam. Excavations in the river channel for the dam and powerhouse were carried downward a maximum depth of 135 feet below the old river bed. A piece of 2- by 6-inch cut timber was uncovered 40 feet below the river bed, indicating the depth to which the river had eroded its channel during some flood or floods in the last 50 years.

Removal of loose and projecting rock from the canyon walls and the excavations for the intake towers, dam abutments, back walls of power house, and the valve house benches were conducted by the spectacular high scaling methods. Ropes were fastened to anchors along the canyon rims and men, suspended from the ropes by safety belts or on bosun chairs, pried off all loose rock and drilled for blasting. High scalers were lowered to their work by cableway or climbed to that position "over the ropes." Approximately 930,000 cubic yards of rock were dumped into the canyon by these methods.

Inclined shafts, from outer diversion tunnels to spillway channels, and the raises to all four intake towers were excavated by first driving a top heading from the lower tunnel upward, enlarging the slot across the section to the invert, and then breaking the sides into the slot, working from the top downward on horizontal benches. Muck was removed from the tunnel below by an electric power shovel and fleet of trucks. Lining the inclines with a 3-foot thickness of concrete progressed from the lower tunnel upward. Concrete was brought to the canyon rim in 4-cubic-yard "agitator" buckets, lowered by cableway or derrick to the upper portal and then placed in position behind steel or wooden forms via zig-zag chutes or by lowering the "agitator" by rail down the incline invert to a belt conveyor which carried the concrete to the forms. Linings of the penstock tunnels and the horizontal sections of the header tunnels were placed by means of conveyor belts or "Pumpcrete" guns.

Concrete for the intake towers was placed by 15-ton derricks equipped with 180-foot booms which took the loaded bucket from train or cableway platform and lowered it to a centrally located hopper on the tower. From here the concrete flowed to place through radially located chutes. A similar arrangement was employed for building the power house and valve houses, cableways being used in place of derricks. Equipment for lining the spillway channels and constructing the weirs consisted primarily of train, truck, and cableway for transportation in 4-yard buckets from the Hi-Mix plant, and a dragline equipped with an 100-foot boom for conveying the concrete by 1-yard bucket to the pouring site.

But it was in the huge mass of the dam that the cableways, mixing plants, and transportation facilities received full play. Concrete was loaded into 8-cubic yard bottom dump buckets and transported to pouring site first by train, consisting of a compartment car pulled by an electric or gasoline locomotive, and then by one or another of four 25-ton cableways. On June 6, the first bucket of concrete was dumped for the huge structure of the dam. Six months later

a million yards were in place, another million was poured in the following half year, and the third million on December 6, 1934, only 18 months after the first bucket dumped its load of concrete 700 feet below. Crest height was reached on March 23, 1935, and by the following summer all concrete—3,250,000 yards of it—was in place, with the exception of the filling of temporary galleries. A remarkable record—1,200 men with modern equipment had in 21 months built a structure whose volume is greater than the largest pyramid in Egypt, which, according to Herodotus, required 100,000 men 20 years to construct.

The contract with Six Companies, Inc. allowed 7 years to complete the work, but by the aid of an efficient personnel, and with the assistance of the most modern equipment, the contract is expected to be completed nearly 2 years in advance of the expiration date. Work remaining to be done by the contractor on October 1, 1935, was principally in the adding of the final touches to major structures, filling the temporary galleries of the dam with concrete, completing the two tunnel plug outlets, pouring concrete piers, anchors and thrust blocks for the plate steel penstock pipe and removing the debris of construction.

New problems arose from the decision to place steel pipes in tunnels for supplying water to outlet works and power-house turbines. The principal provisions of the contract given to the Babcock & Wilcox Co., of Barberton, Ohio, for its low bid of $10,908,000, were to furnish and place 2¾ miles of plate steel pipe, whose maximum thickness of steel was nearly 3 inches, and whose gross weight exceeded 44,000 tons. As mentioned, in part, previously, the penstock header lines are 30 feet and 25 feet in diameter, penstocks of 13 feet (excepting 108 feet of 9-foot diameter), and the outlet conduits of 86-inch and 102-inch diameter.

Railroad facilities were inadequate to transport the larger pipe sections, and therefore a modern fabrication plant was built at a suitable location along the United States construction railroad, 1½ miles from the top of the Nevada dam abutment. Flat plates were shipped to the plant and the pipe sections entirely fabricated there. A section of the largest pipe when completed had a length of 23 feet 4 inches and a weight of 175 tons.

Fabrication of a 30-foot section consisted essentially of marking six 10-foot 6-inch by 31-foot 5-inch flat plates, cutting them to size with an acetylene torch, planing welding grooves on three sides, preparing the plates for rolling by bending the ends in a 3,000-ton press, rolling the plates in 12-foot vertical rolls, assembling and electrically welding the plates together and adding butt straps and stiffeners. All welds between the rolled plates were then X-rayed

by a 300,000-volt portable machine, the film examined, all flaws chipped out and replaced with new metal, and the weld X-rayed again. The pipe was then taken by one or more 75-ton traveling cranes to the normalizing furnace where it was heated to a temperature of 1,150° F., held at this temperature for several hours, and slowly cooled to relieve the stresses set up by rolling and welding. From the furnace, the section traveled to a facing lathe equipped with a 35-foot arm, where the pipe ends were machined, and the section then taken to the storage yard for cleaning, painting, and the drilling of holes for erection pins. Fabrication of all pipes is expected to be completed in 1935. Items of interest, relating to the work, are that there will be approximately 76 miles of welding and the X-ray film used will be 29 miles in length.

Transportation of sections from plant to canyon rim was by train for the 13-foot diameter pipes and smaller ones, and by a 200-ton trailer pulled and controlled by two 60-horsepower caterpillar tractors for the heavier sections. The 200-ton Government cableway transferred the pipe from canyon rim to a "car-on-a-car" at the portals of one of the construction adits from where it traveled on the double carriage through the adit to a penstock header tunnel and was pulled to its approximate final position on the top single carriage by suitably located winches.

If the pipe section was intended for a position in one of the raises to the intake towers, the car left the tunnel rails at the base of the raise and traveled on the concrete lining to its place under impetus of three hoists, each of 75 horsepower rating, located on a platform at the tower base.

The procedure of erection was to install spiders in each adjacent pipe section and by means of jacks in the ends of the two spider arms form the pipes in round sections. The butt strap was then heated with a gas ring (using butane gas), one pipe was pulled into the other with winches or a specially devised spider, steel pins were inserted and pressed into place from inside the pipe, a rim was cut into the pipe around the outer end of the pin and this rim calked inward beneath a projecting rim on the pin. The outer end of the butt strap was also calked into the pipe it enclosed. The pins for the largest 30-foot sections were $3\frac{1}{16}$ inches in diameter, and the diameter of the drilled hole, into which they were pressed, was three-thousandths of an inch less than that of the pin.

All pipe sections were pinned, excepting the $8\frac{1}{2}$-foot outlet conduits, which were hot-riveted, and a few miscellaneous sections that were welded. In the latter case, the weld and pipe near it were stress relieved by heating with gas rings.

Erection was started in April 1934 and by January 2, 1935, was in progress in all four tunnels. At the present rate of installation, the entire program of erection will be completed before the end of 1936.

Owing primarily to the progressive manner of its installation, the Bureau of Reclamation elected to place most of the intricate mechanism of the power-plant machinery with its own forces. Four of the 115,000 horsepower units, and one of 55,000 will be placed in the powerhouse, starting in 1935, and two more of 115,000 horsepower in 1936. The other eleven 115,000 horsepower units and one of 55,000 horsepower are expected to be installed within the next few years in accordance with the power contracts.

Although of predominant interest at this time, the activities of construction will soon be nearly forgotten in the all-absorbing interest in the results being obtained from the project and those anticipated.

Today the massive structure of the dam boldly fills the gap between canyon walls. Upstream from the dam, the four spires of the intake towers rise from the reservoir, and on each side of the canyon the large spillways occupy basinlike depressions. Immediately downstream from the dam is the U-shaped powerhouse, and in niches in the cliffs farther downstream are the valve houses of the canyon wall outlet works. Adit portals are visible at the downstream ends of the powerhouse wings and a short distance upstream from the canyon wall valve houses, through which steel pipes are being taken into the penstock tunnels. Down the canyon a few hundred feet, the diversion tunnels open into the river channel, the outer Nevada one now carrying the entire discharge from the reservoir.

Already the blue-green reservoir has filled the canyons for 80 miles where the river long held sway, and lines of tall towers are marching across the desert, soon to carry millions of watts of power to southern California cities.

Imperial Valley needs no longer fear drought and flood, for an entire year's supply of irrigation water is already in the reservoir, and floods above Boulder Dam may be shut off entirely if found necessary. Reports are also received of a considerable lessening of the silt content at downstream points, and the reservoir back of the dam is clear for 25 miles upstream. Boating and swimming are becoming more popular, and the first bass have been placed in the reservoir by the Bureau of Fisheries Hatchery of Dexter, N. Mex.

The Bureau of Power and Light of the city of Los Angeles is erecting two 3-conductor 287,500-volt transmission lines to Los Angeles.

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The Metropolitan Water District of Southern California is commencing construction of a line to take power from the dam to pumping stations 125 miles to the southwest. Communities in Nevada, as many as 150 miles away, are already making efforts to obtain the cheap power that will soon be generated. An electrochemical laboratory is expected to be established in Boulder City shortly to aid in the development of the mining areas in the nearby regions.

Boulder Dam was dedicated on September 30, 1935, by President Franklin D. Roosevelt in a ceremony which was attended by Secretary of the Interior Harold L. Ickes, several Senators and Governors from the Colorado River Basin States, high officials of the Bureau of Reclamation, and many prominent persons whose names are linked with the Colorado River conflict and the development of the Southwest.

The question is often asked "Who planned this great works?" and the answer must be "No one man." It represents the combined training and experience of engineers of the Bureau of Reclamation gained in 30 years of building similar structures. In the days when the project was in its formative period, A. P. Davis was its director and F. E. Weymouth chief engineer. During the later years, and throughout construction, the Commissioner of the Bureau of Reclamation has been Dr. Elwood Mead; the chief engineer, R. F. Walter; assistant chief engineer, S. O. Harper; chief designing engineer, J. L. Savage; chief electrical engineer, L. N. McClellan; and chief mechanical engineer, C. M. Day. Construction engineer Walker R. Young is in charge of construction on the project.

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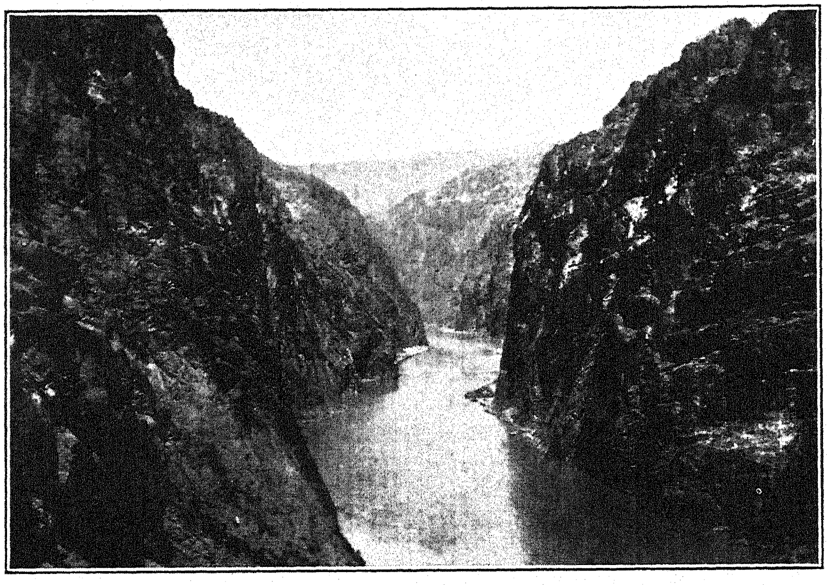
Compressed Air Magazine: The Story of Boulder Dam.

Boulder Dam Service Bureau: Construction of Boulder Dam, seventh edition.

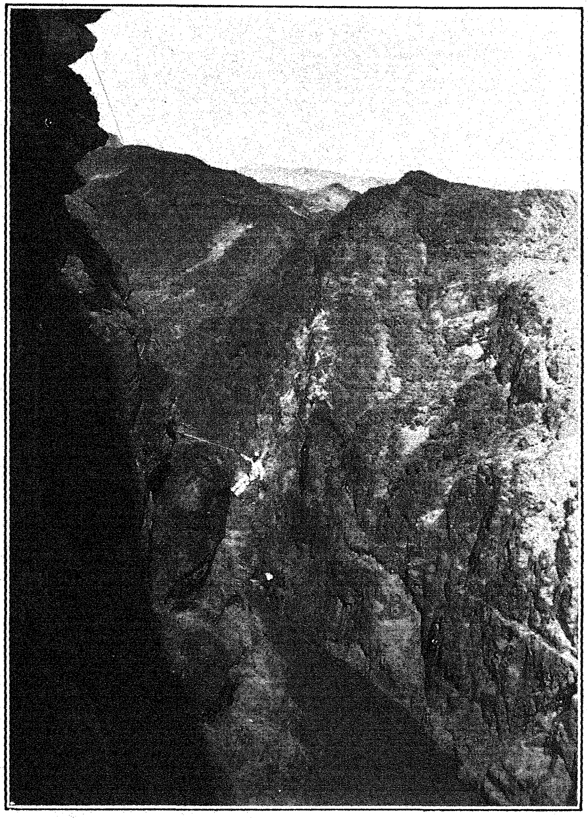


1. LOOKING UPSTREAM THROUGH BLACK CANYON TOWARD DAM SITE.

Copy of photograph taken in 1922.

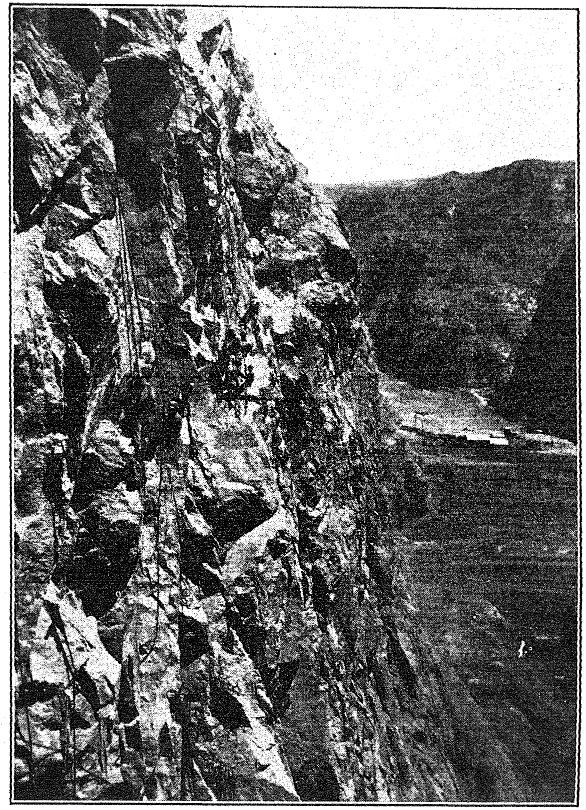
2. LOOKING DOWNSTREAM TOWARD DAM SITE FROM LOWER SLOPE OF UPPER COFFERDAM.

Base of Nevada intake towers excavation seen in upper right. December 31, 1932.



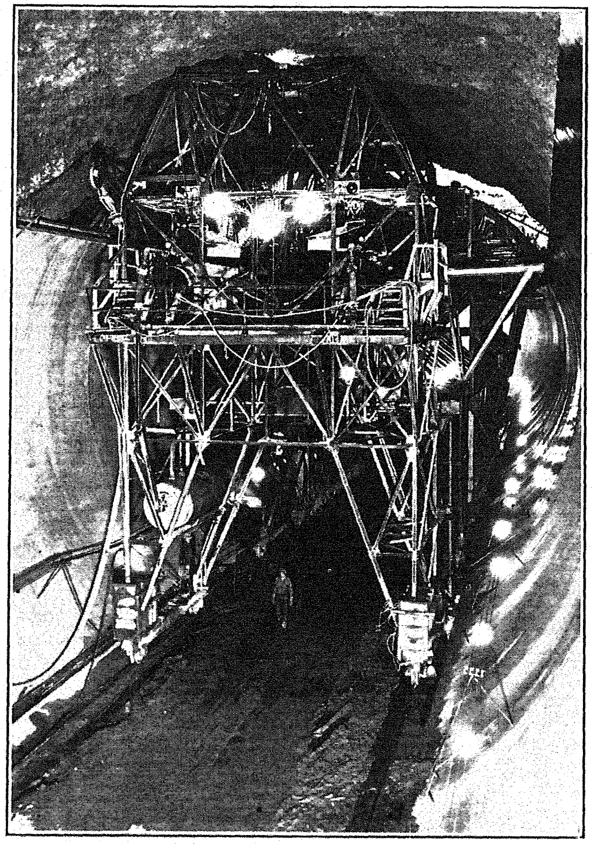
1. RIGGER RODMAN WORKING WITH TOPOGRAPHY SURVEY PARTY IN BLACK CANYON ON NEVADA SIDE.

Rodman is lowered over canyon rim on rope. April 15, 1932.



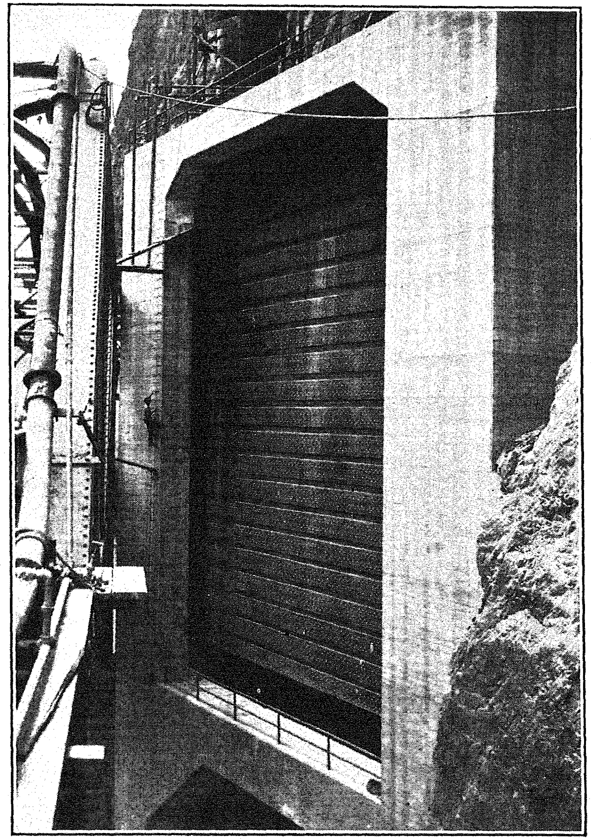
2. HIGH SCALERS CLEARING CANYON ABOVE NEVADA POWER PLANT SITE.

May 25, 1933.



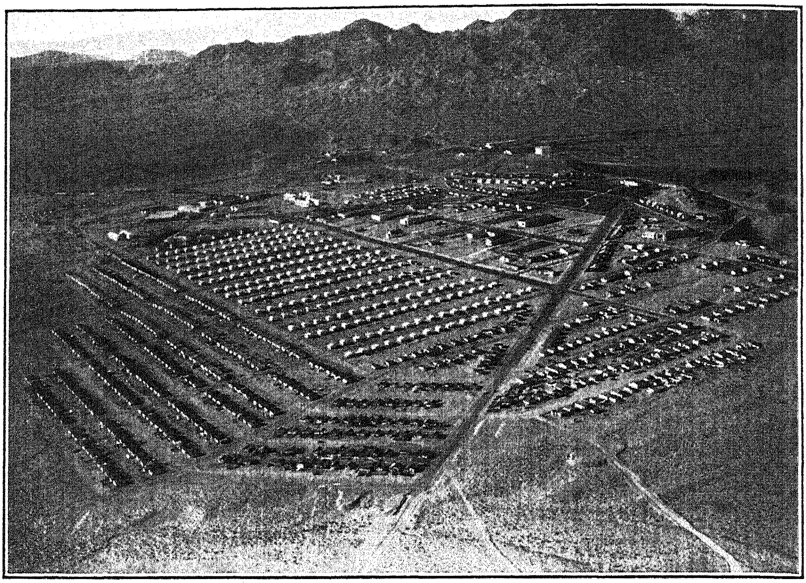
1. CONCRETE GUN CARRIAGE USED IN PLACING 110° TOP ARCH CONCRETE IN DIVERSION TUNNELS

June 30, 1932.



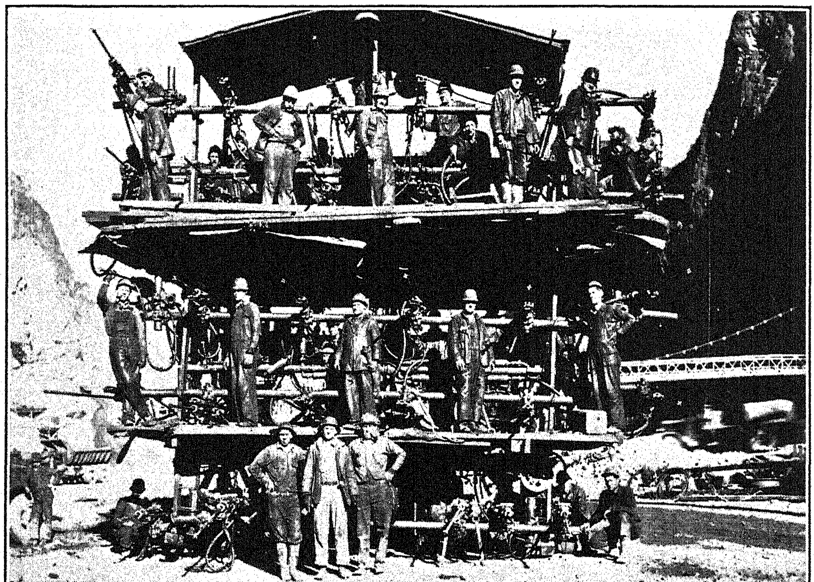
2. BULKHEAD GATE AT ENTRANCE TO DIVERSION TUNNEL NO. 1 IN RAISED POSITION.

May 10, 1934.



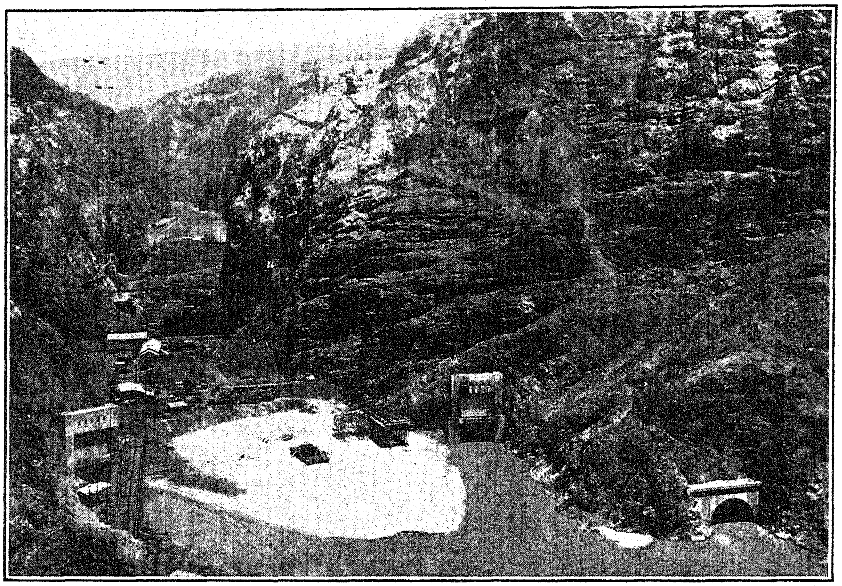
1. HEADQUARTERS OF BOULDER CANYON PROJECT, SEEN FROM THE AIR. BOULDER CITY, NEV.

View looks northwest. December 13, 1934.

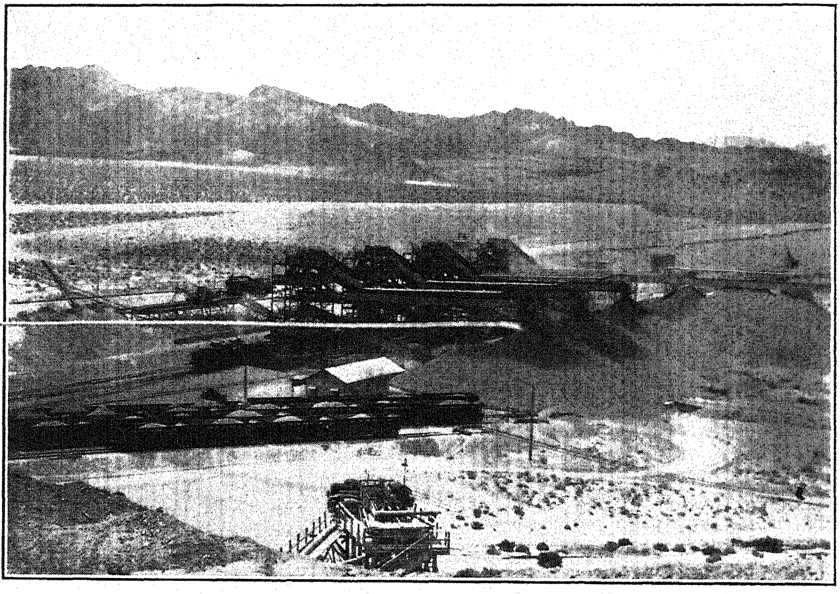


2. TRUCK MOUNTED DRILL RIG USED BY CONTRACTORS IN UPPER PORTION OF DIVERSION TUNNELS.

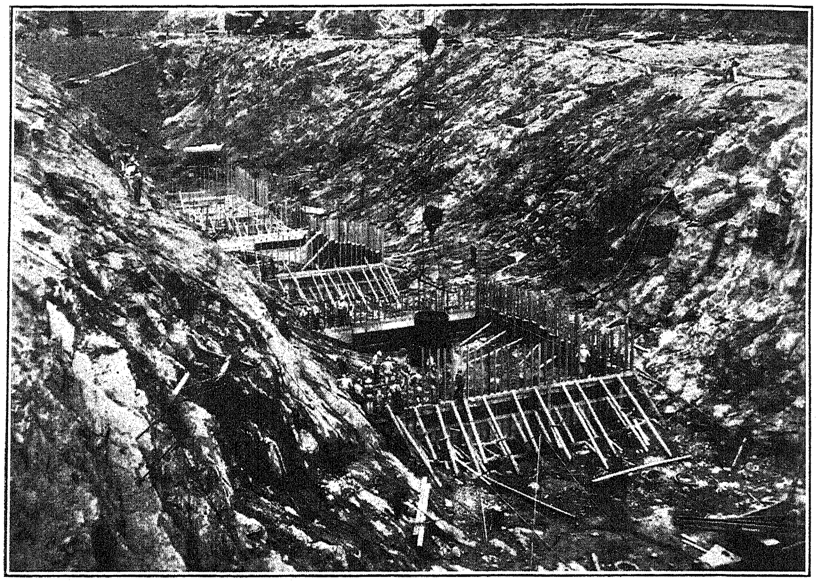
Rig is seen in the position in which it approaches heading. April 20, 1932.



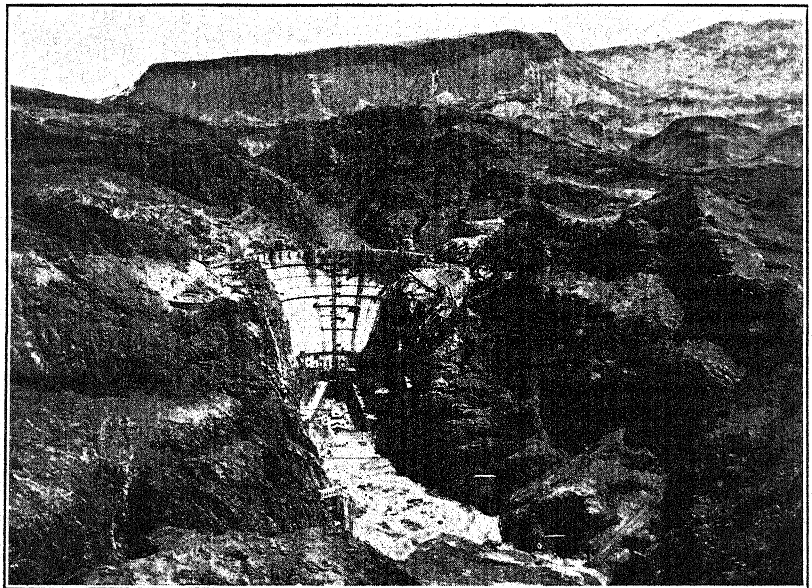
1. LOOKING UPSTREAM THROUGH BLACK CANYON.
View shows outlet portals of diversion tunnels nos. 2, 3, and 4. July 28, 1933.



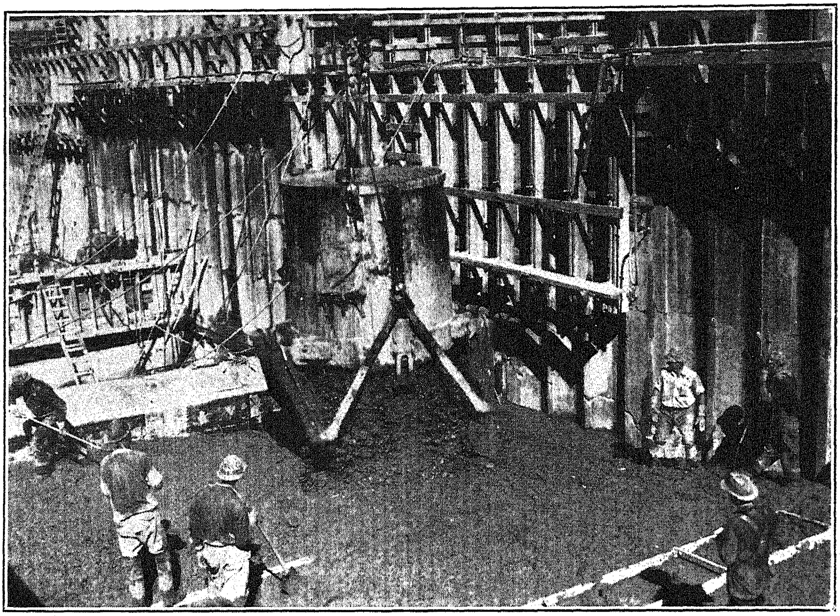
2. GRAVEL SCREENING AND WASHING PLANT.
July 17, 1933.



1. FIRST BUCKET OF CONCRETE GROUT IS PLACED IN BOULDER DAM PROPER.
June 6, 1933, 11:20 a. m.

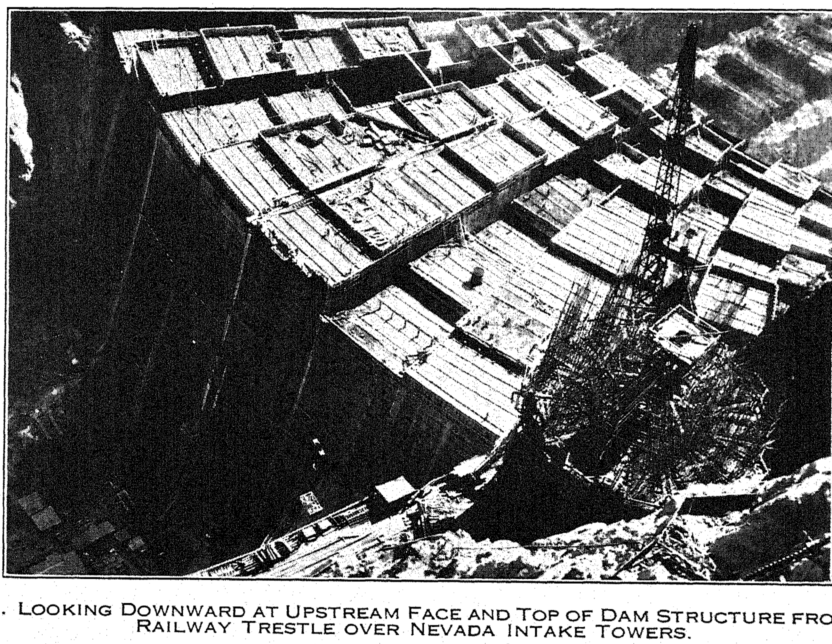


2. DOWNSTREAM FACE OF BOULDER DAM.
The last dump of concrete was poured on May 29, 1935. Work is still in progress on power plant.



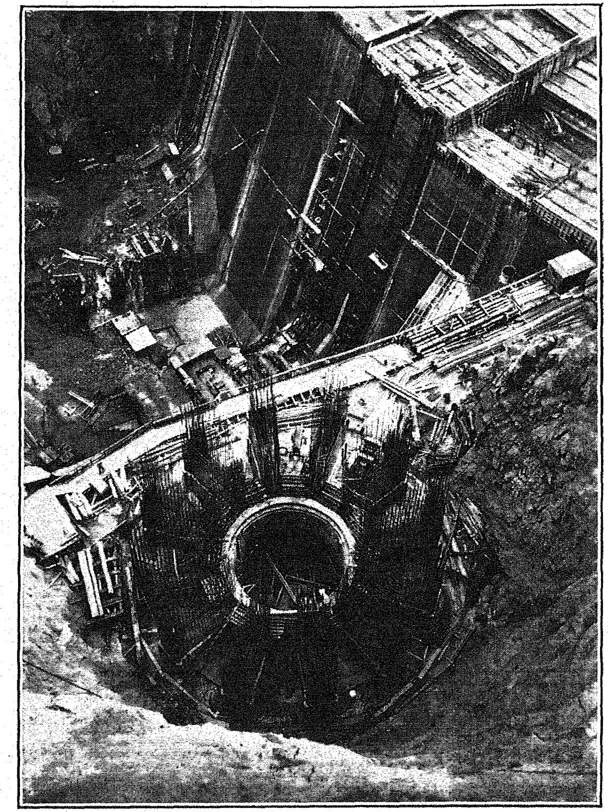
1. EIGHT CUBIC YARD CAPACITY CONCRETE BUCKET DISCHARGING LOAD IN DAM COLUMN FORM.

September 27, 1933.



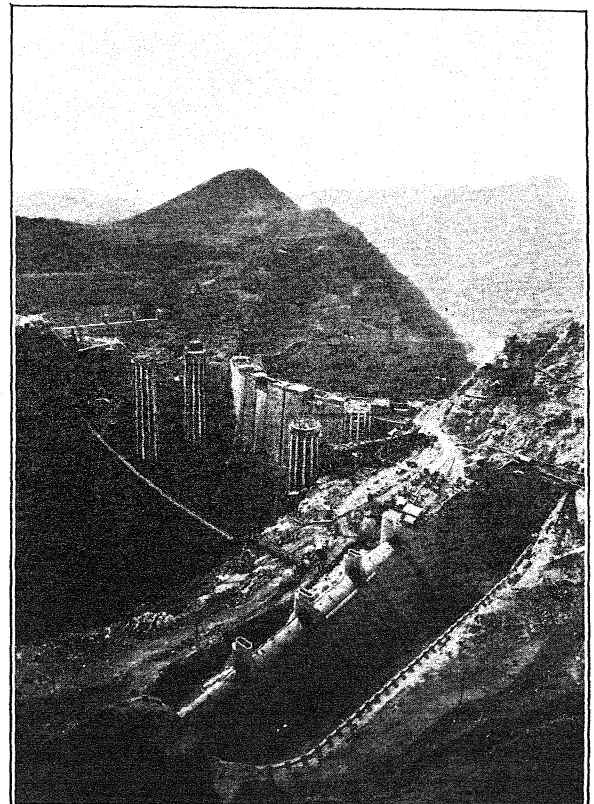
2. LOOKING DOWNWARD AT UPSTREAM FACE AND TOP OF DAM STRUCTURE FROM RAILWAY TRESTLE OVER NEVADA INTAKE TOWERS.

March 22, 1934.



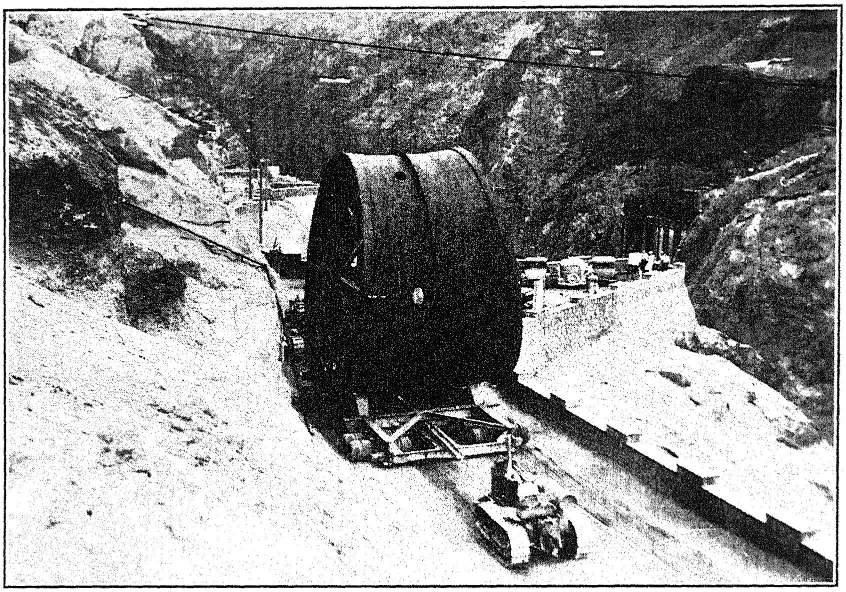
1. LOOKING DOWN ON UPSTREAM NEVADA INTAKE TOWER.

Upstream face of dam in canyon below. February 23, 1934.



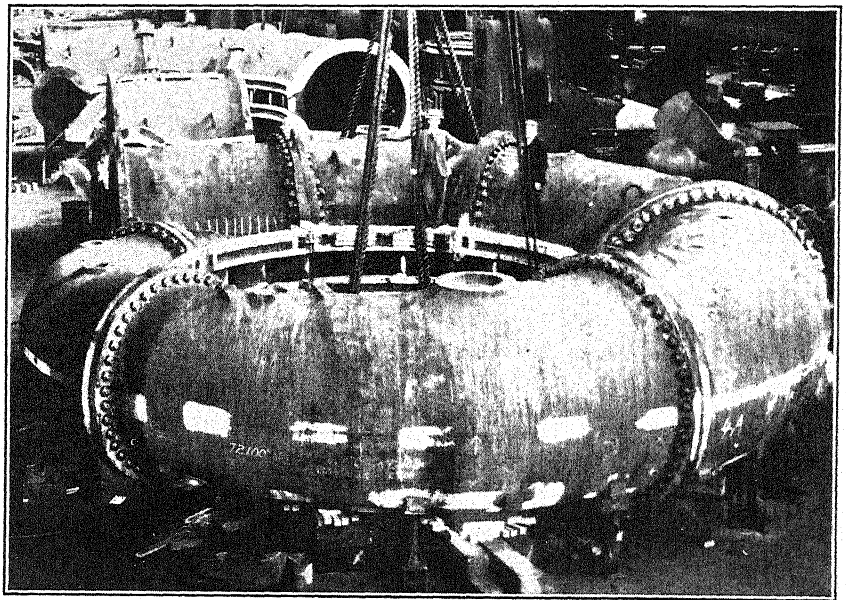
2. GENERAL VIEW OF UPSTREAM FACE OF DAM AND APPURTENANT WORKS AS SEEN FROM HIGH POINT ON NEVADA RIM OF BLACK CANYON.

December 31, 1934.



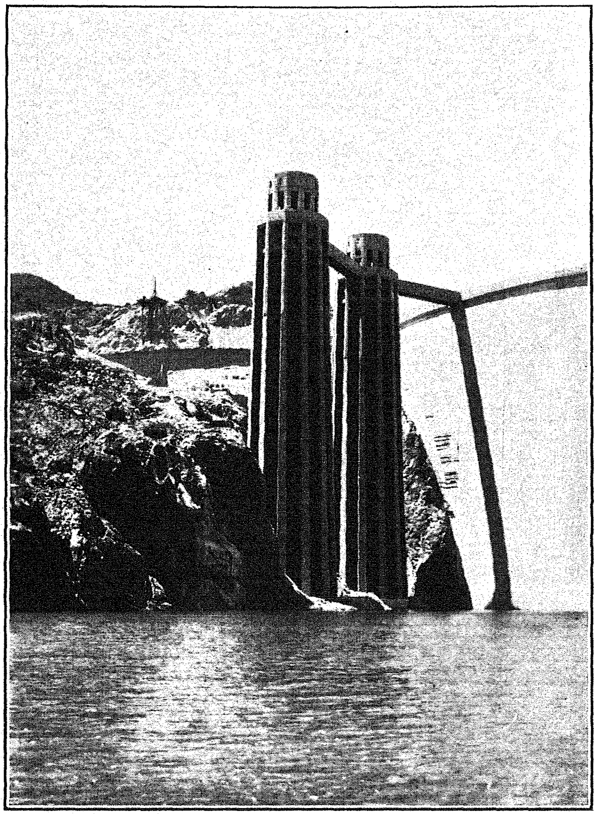
1. HAULING FIRST SECTION OF 30′ DIAMETER PENSTOCK PIPE ALONG PARAPET ROADWAY.

July 20, 1934.



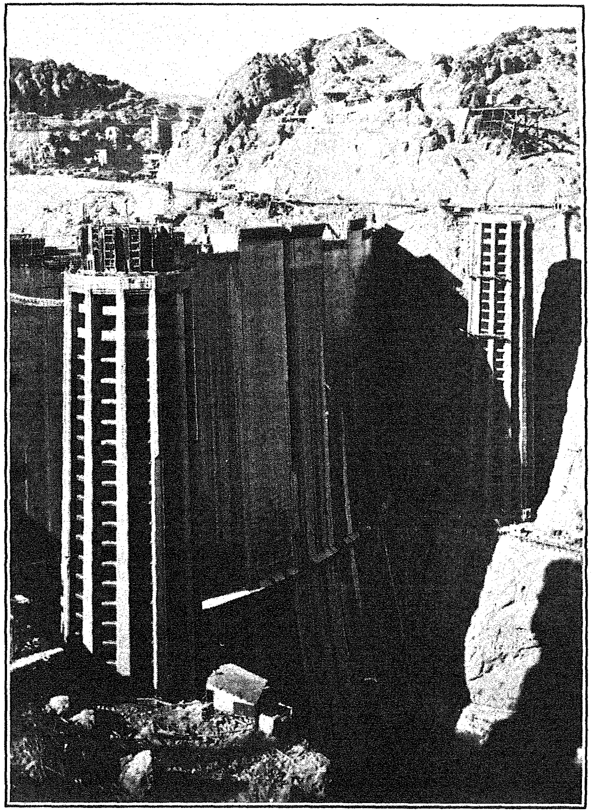
2. STEEL SPIRAL CASING FOR 115,000 HORSEPOWER BOULDER POWER PLANT TURBINE ASSEMBLED IN SHOP OF ALLIS CHALMERS MANUFACTURING CO., MILWAUKEE, WIS.

May 15, 1935



1. ARIZONA INTAKE TOWERS AS SEEN FROM SURFACE OF RESERVOIR

June 21, 1935.



2. THE UPSTREAM FACE OF THE DAM AND THE TWO DOWNSTREAM INTAKE TOWERS AS SEEN FROM ARIZONA RIM OF BLACK CANYON.

February 2, 1935.

WINGS OVER THE SEA:[1] ARE LANDING PLACES NECESSARY FOR THE COMMERCIAL AERIAL CROSSING OF THE NORTH ATLANTIC?[2]

By Louis Blériot

[With 5 plates]

The recent progress of commercial aviation: the speedy transcontinental lines in the United States, the renewing from the ground up of the equipment of the great European transport companies, the success of the London-Melbourne route, as well as the regular crossings of the South Atlantic—all this shows that development is accelerating and that aviation is moving with great strides toward its final goal, supremacy in the field of rapid transport over great distances.

Everyone remembers the magnificent flight of Costes and Bellonte, September 1 and 2, 1930, one of the finest performances of the times, a response to the visit of Lindbergh and the first flight from Paris to New York, made under extremely difficult conditions. I salute also Rossi and Codos, who in the *Joseph LeBrix*, in 1933, succeeded again in crossing the North Atlantic, carrying a useful load of 2 tons. It is to them and to Bossoutrot that I owe the present list of honors of my old firm—world records in a straight line and in a closed circuit, and crossings of the North and South Atlantic in both directions. Let me express here my recognition and my admiration for your intrepid courage.

I recall that it was in 1919 that the Atlantic was first crossed in an airplane by Alcock and Brown. You will remember the flight of Lindbergh, coming in a straight line from New York in 1927, and today we can say that the list of pilots who have succeeded in this exploit exceeds by far the hundred mark, the Italians having crossed in a squadron with a personnel of 100.

Many of these heroes have visited me, and it is after conversing with them that I have decided, in order to do my best to aid them, to

[1] Translated by permission from l'Aérophile, 43e ann., no. 3, March 1935.

[2] This matter has been made the subject of a conference at the Aero Club of France.

try to solve that great problem worthy of French aviation: the commercial aerial linking of our two continents.

Let us commence, then, the study of the problem. If we consider the component elements of all transport—(1) speed, (2) economy, (3) frequence, (4) regularity, (5) safety—we see immediately that on all these points transoceanic aviation is rapidly coming to outdistance all the other means of transportation.

SPEED

It is undeniable that the airplane can now make 250 to 300 kilometers an hour, thus joining Europe to America in 16 to 20 hours. There is therefore no need to insist on this point.

ECONOMY

Maritime companies, under the influence of international competition, are forced to build enormous floating palaces more and more expensive and more and more comfortable, but of which the cost runs into astronomical figures. Modern steamships such as the *Queen Mary* and the *Normandie* cost more than 800,000,000 francs, which for a total of 2,000 passengers represents for each passenger a capital of 400,000 francs, whereas for an airplane this same capital would be in the neighborhood of 100,000 francs. As an airplane travels four times faster and hence can cross the ocean two or three times a week, while a steamship can make the crossing only two or three times a month, we can see how much greater would be the return on the capital involved in the case of the airplane, and this in spite of the difference in amortizement.

It appears that at present we are seeing a sudden change in the technique of transportation. We are struck by the importance of dead weight necessary in providing for the comfort of the passengers. In de luxe trains the transportation of a traveler represents a dead weight of several tons, and the coefficient of utilization is perhaps even less than 2 percent. This coefficient is reduced to 1½ percent or even less in the great steamships. Thus it is seen why we seek to obtain a better result and why we come to busses or to automobiles, which transport a useful load in the neighborhood of 20 percent, with therefore a decrease in the cost per kilometer.

While on the subject of economy, I would like to bring out here the role of dead weight in aviation, a role entirely different from that in terrestrial or marine transportation. To transport passengers means, in the first case, to transport a certain weight; and in the second case to overcome the air resistance of the railway coach or of the cabin, of which the design is conditioned by the exigencies of comfort.

Since there are now constructed, according to the principles borrowed from aviation, fusiform trains and also aerodynamic pilot houses, it may be said that the air resistance, for equal speeds, would be practically the same for the means of transportation on the ground as for the airplane. But it is not the same for the resistance due to the weight to be transported.

For an automobile, the resistance to horizontal motion, or resistance to rolling, is about 25 kilograms per ton; for railroad trains and great steamships, it is about 2 kilograms per ton. Now, in aviation, this coefficient is infinitely greater; it corresponds inversely to the superiority of the wing structure. In spite of all the progress of aerodynamics, the necessary traction is at least one-twentieth of the weight to be transported, say 50 kilograms per ton. It is therefore twice as great as for the automobile, 25 times as great as for the railroad train and the ship. If we see great efforts already being made to lighten rolling stock, this lightening becomes a necessity in aviation, where the dead weight is brought to life; it has a good appetite, for it needs a large ration of fuel.

For the airplane it is necessary that the ratio of useful pay load to dead weight be at least 20 percent, if it is not to fall into the class of excessively high-priced transportation. I must admit that for the mail plane we can be content with much less, but it should not be supposed that we will always carry the mail at a tariff of 2,000,000 francs a ton, as is the case at present for the France-South American mail. This mail will become lighter, for soon it will be divided among the countries located on the same route, and more and more it will be subject to the competition of the radio.

It will therefore be necessary to consider a less remunerative freight. The difficulty for the great ocean routes will then be to reserve for this freight at least 20 percent of the weight of the airplane. In this case, as it is necessary to count on about 60 percent for the weight of the airplane and of its motors and equipment, there would remain therefore only 20 percent for the weight of the fuel; this would limit the hops to about 1,500 kilometers, which can now be accomplished at speeds of 200 to 250 kilometers per hour.

FREQUENCE

Aviation need only construct units with a capacity of 20 to 25 passengers which would be sufficiently comfortable for a trip of several hours. The transport plane, therefore, can be full on each of its trips, even if these trips are daily, while a steamship with a capacity of 2,000 is not assured of having its full complement of passengers on each of its weekly trips.

REGULARITY AND SAFETY

These are the principal conditions for a commercial undertaking. They are conditioned by the ground facilities. The experience of terrestrial aviation has clearly shown that its development is closely connected with that of the organization of airports.

If the transcontinental lines in the United States have had such a brilliant success, it is due to the some 1,600 airports, veritable service stations, which line all the aerial routes. And if these routes stop short at the shores of the oceans, it is for no other reason than that the ground facilities stop at the same places.

The effort which must be made to provide these ground facilities is still considerable. I call upon the qualified organizations and upon all those interested in this question for the diplomatic and financial solutions of the problem here considered, for I will show you shortly that it has been solved technically. I may add that it is necessary to hasten, for competition is already appearing between Zeppelins and steamships.

I was recently in New York at the same time as Dr. Eckener, who announced in public lectures a Zeppelin service for the month of June following to make the crossing from Europe to North America in 48 hours, as he had already joined South America to the Old World. These Zeppelins could carry about a hundred passengers and several tons of freight. I have heard it said, moreover, that America, not wishing to be outdistanced, is constructing two Zeppelins for the same purpose. Certainly these Zeppelins can never obtain the speed of airplanes, but this does not mean that they will not some day rival them from the point of view of regularity, of safety, and even of economy.

HISTORICAL

Let us speak a little of the history of the question. Going back to 1927—in that year I submitted to M. Bokanowski, then head of the Ministry of Public Transport, to which aviation was attached, the result of my work in the form of a memoir. On the subject of the route the conclusion was definite: It is absolutely necessary to pass to the south of the bad-weather zone, a line which we now know so well, thanks to the remarkable work of our two meteorologists, MM. Wehrlé and Viant. French aviation owes them the highest recognition for the exact advice which they have always furnished to our military pilots and to those of my firm in particular, realizing that a good part of their success is due to the devoted collaboration of these two men of science.

On the subject of equipment, I proposed very special airplanes, which I will describe to you shortly.

The official services have not felt that they should give attention to my work. I found support, then, from a great motor firm, "La Société française Hispano-Suiza." In 1928 we sent to the Azores our joint representative, the engineer M. Heurteult, later director of the Columbia Co. and son-in-law of M. Birkigt, to study on the ground the possibilities of establishing the proposed landing place. He found a suitable site for the location of an airport, but before being able to undertake anything, it was necessary to get the consent of the Portuguese Government. There again the lack of official interest on our part stopped short all private initiative, in spite of the intervention of an interested deputy of French aviation, M. Forgeot.

Since then, other French firms have interested themselves in this landing place in the Azores, while I have concentrated all my efforts on a more complete solution, making considerable progress and avoiding more easily difficulties of a diplomatic nature: That of floating islands.

THE FLOATING ISLANDS

Numerous projects, in France as well as abroad, have been worked out in this connection, most of them unfortunately somewhat fantastic. I cite as an example the projects of two French architects, M. Defrasse and M. Basdevant: The first concerns a floating island of reinforced concrete, forming a horseshoe; the second contemplates two pontoons joined by a bridge. These are not, however, floating airports, but simply landing places for the refueling of hydroplanes, and the special form proposed by the authors of the plans has for its purpose the creating of a stretch of water calm enough to permit landing even in bad weather.

I consider that the only project that would be perfect from all points of view is that of the Armstrong Seadromes.

That American engineer has been actively occupied with the question for about 15 years. He has not been content with making successive plans, answering better and better the criticisms and suggestions that have been made to him by the eventual users. He has not only studied with very exact care all the details of construction, solved in clever fashion knotty problems such as stability in the water, independence of the motion of the waves, anchorage in a depth of more than 4,000 meters, the transportation of these structures to their determined stations, and many details of arrangement—no, he has done more—with the support of the research association which he created, he has completed models, reduced in scale it is true, but nevertheless devices weighing several tons. He has tested

them in agitated water, thus verifying the soundness of his predictions.

An Armstrong seadrome is a great platform constituting the landing area for airplanes and supported by a certain number of columns.

There are two superposed decks: The upper one forms the landing platform 475 meters long by 92 meters wide in the center and 46 meters wide at the ends. An elevator permits the airplane to descend to the lower deck, where are found spacious hangars, repair and maintenance shops, dwelling quarters for the crew, stores, auxiliary equipment, as well as hotel accommodations for the passengers, a certain number of whom, one would think, would wish to spend several days in the calmness and the pure air of the ocean, only 8 hours from Paris, London, or New York.

The upper deck, which is located 31 meters above the water, is kept as clear as possible so that nothing may hamper the airplanes. The lookout station and the antenna of the directional radio, installed completely above the deck, are the only protuberances. The ensemble of the two decks forms a solidly braced metallic framework which rests on 32 sheet-iron columns. Each of these is furnished with a watertight reservoir, filled with air and forming a float, with another reservoir at its lower end filed with iron ore serving as ballast for the sake of its stability. It is in the judicious disposition of these floats that resides the great superiority of the Armstrong seadrome over all other known projects. It will, then, be desirable to dwell a little on this point. The wave which you see shown in the drawing (fig. 1) is 9 meters in height by 180 meters in length; this is a degree of roughness greater than would be seen even during a gale; as you see, not even the lower deck is reached by the water.

The amount of motion of the water produced by the waves decreases rapidly, however, below the surface. The floats, then, are located in relatively calm water—like submerged submarines; the result is that the supporting effort on the whole structure varies hardly at all—so little that there is no pitching motion. There is produced only a slight heaving, of the order of several centimeters.

In actual use the lower ends of the columns are 63 meters below the water level. In towing the seadrome to the place where it will be used, this would be much too great. The columns are therefore telescopic; during transportation the lower part is raised so that they draw only 16 meters of water.

In order to remain in the desired location, the seadrome is secured first to a buoy, which in turn is fastened to an anchor of special form. The maximum pull exerted by the water and by

the wind has been determined after tests in the laboratory and in the open as 60 tons. The reaction due to the waves has been reduced to the minimum by giving a fusiform shape to that part of the columns which projects above the water. To anticipate, nevertheless, a situation in which the seadrome, following a break in the mooring cable, should find itself adrift, there have been installed a group of four motor-driven propellers; each comprises an electric motor of 500 horsepower, driving a propeller about 6 meters in diameter. The speed of 6 knots which this system makes possible is enough to overcome drift, and it can also aid during transportation.

The type of anchor which, after many trials and much study, the Armstrong Co. has employed, has a circular form 30 meters in diameter and weighing 100 tons. The maxmium depth on the route selected is about 4,500 meters. The connection between the buoy and the anchor consists of two cables, the diameter of which is about 80 millimeters at the top, decreasing to about 65 millimeters at the lower end and terminating in two chains.

In case it should not be desired to put all the seadromes into operation at one time, the Armstrong Co. has developed the project of an intermediate floating island; it constitutes a meteorological and radiogoniometric base, carrying a powerful beacon. The anchorage comprises the same elements as that of a seadrome; the replacement of one by the other, therefore, would be very rapid.

Having spoken of the floating islands themselves, we now come to their utilization.

THE AIRPLANE

A trial bifuselage airplane, specially designed for this service, was constructed in 1930 and has shown itself to be very manageable. It performed very creditably, considering the very modest power of the motors with which it was equipped. The results obtained have furnished a sure basis for the extrapolation of the formula from which was constructed a model for trial in the wind-tunnel. The two watertight fuselages have tapered bottoms, in order to permit contact with the water without dangerous shock. The three motors are installed on the trailing edge of the wing, which leads to numerous advantages: An improvement in the operation and efficiency of the propellors, quietness in the cabins, suppression of all risk of fire from the motors, excellent visibility for the pilots, etc.—which are added to the previously known advantages of the bifuselage formula: Lightness and strength of construction, due to good distribution of weight, the elimination of the aerodynamic resistance of the wheels, without which it would be necessary to

have recourse to retractable landing-gear, extreme comfort of the passengers, etc.

The hydroplaning surfaces can be attached to the bottom of the fuselages after the airplane is put down on the water. This arrangement permits the airplane to rise from the water with a light load in order to regain the nearest airdrome or seadrome.

As you see, I have always remained faithful to the airplane for these great commercial routes. The reasons which have lead me definitely to adopt this solution are the following:

All things being equal, the airplane has greater commercial efficiency, for the weight and the resistance of the fuselage are always less than those of a hull furnished with pontoons permitting it to take off.

Furthermore, the safety of a hydroplane is not greater than that of a multimotored airplane, provided that the latter can land on water without danger and remain afloat for a sufficiently long time. As a consequence, a multimotored airplane would rarely be so completely crippled as to be unable to get back on the air lane. If such were the case, however, the damage is certainly irreparable with the facilities at hand, and the ability of the hydroplane to take off again does not therefore give it any marked advantage.

Finally, the operation of taking on and discharging passengers is much slower with a hydroplane than with an airplane.

These are then sufficient reasons to explain my preference for the airplane in the form of a marine airplane; that is, one being able to land on the water and even to take off again if lightened.

AIRPLANE CARRIERS

A few words should be said about airplane carriers, which some propose instead of floating islands. They would not be able to render the same services, for in the first place the reduced dimensions of their platforms, although sufficient for combat or reconnaissance airplanes, would not be so for the great commercial airplanes heavily loaded. Furthermore, they could be used only with difficulty in bad weather, as like all boats they follow the motion of the waves, and the necessity of having their boilers always under pressure to prevent drifting would make their use very burdensome. I will not therefore speak of them further.

On the map (pl. 1) you see the proposed positions of the seadromes, in particular the four which will make the bridge between Europe and North America. You see that the distance which separates them, and from them to the continents, is 600 to 650 miles, say about 1,000 kilometers.

FINANCIAL PLAN

Permit me now to give you some details on the financial side of the enterprise. Each island will cost about 110 million francs, say, for the four, 440 millions—let us put down 500 millions. How will this capital be rewarded? It will be:

1. By the mail: Of the 3,000 tons of letters now carried it is estimated that 500 tons would be destined for airplanes; of the 26,000 tons of packages and printed matter it is estimated that 800 tons would go by air mail. Two-sevenths of the receipts will go to the floating islands and will yield 90 million francs a year.

2. By passengers: Statistics say that the North Atlantic is crossed every year by about a million travelers, of whom about 80,000 use the modern steamships, paying for the crossing an average of 7,500 francs each. By airplane the cost would be about 5,250 francs, of which 1,050 would go to the credit of the seadromes. We predict, for all countries, in normal use, four trips a day in each direction, each airplane carrying an average of 20 passengers. This would make, therefore, 160 passengers a day, or an income of 60 million francs a year.

The other receipts would come from the sale of gasoline and oil, from the renting of hangars and stores, from hotels, etc., and their increasing total is estimated at 12 million francs a year.

The total revenue of the four seadromes thus reaches 170 million francs. From this income there should be deducted about 30 million francs for operating expenses, the salaries of the personnel, and insurance premiums. There remains, in the end, a net revenue of 140 million francs a year on an invested capital of 500 millions; it is therefore a good paying proposition.

For its realization there is proposed a national association for each country, which will construct one island. This project will provide employment for 3,000 or 4,000 workmen for 18 months. The different associations will belong to an international association, administered by either the League of Nations or the International Aeronautical Federation; its island and the operating company will pay to each of the national associations its part of the benefits.

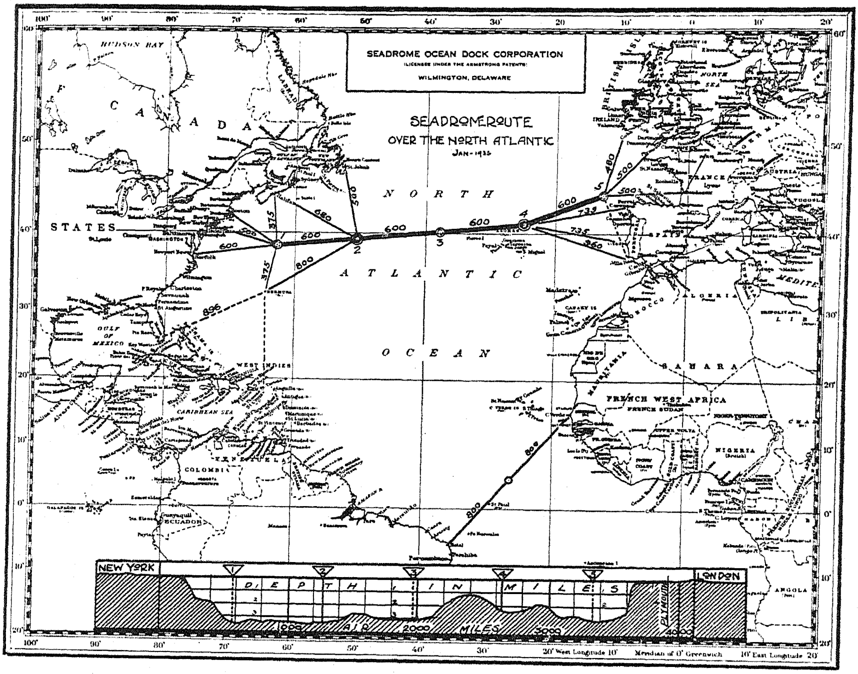
The amount of the capital involved, as well as the newly created relations between the coastal nations, will assure the internationalization of this affair. These same reasons will also be a sufficient guarantee against the eventuality of a competing line using other floating islands.

CONCLUSION

I will close this article by insisting, once more, on the great importance of the regular aerial crossing of the North Atlantic, an importance which can be compared only to that of the Suez or the

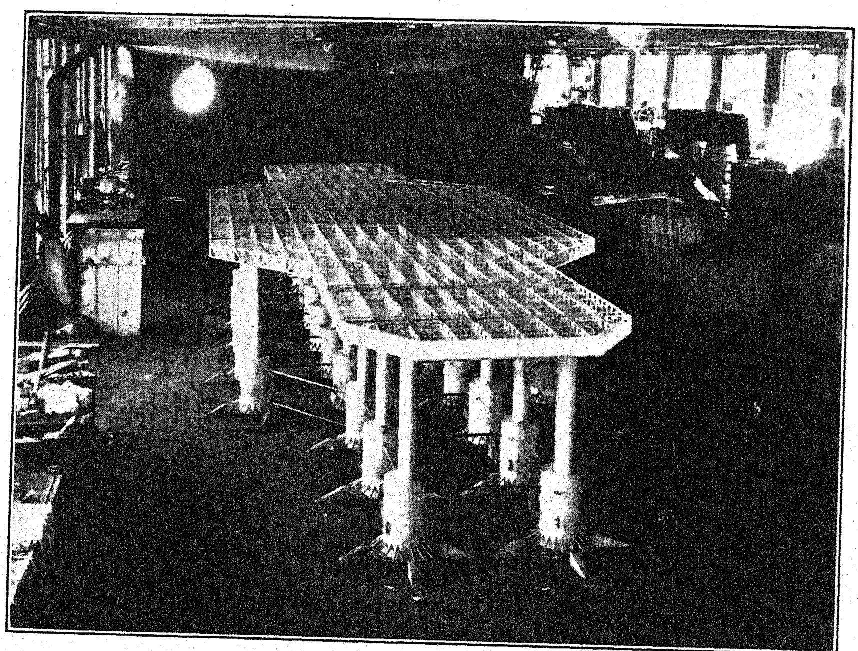
Panama Canal, with this difference—that it will be realized in a much shorter time. The question is no longer whether or not the regular aerial crossings of the North Atlantic will be made, but whether France will have in it the place which she deserves. Some believe the plan to be too bold—but audacity, when it is deliberate, is the mother of all progress; it alone is capable of putting in the vanguard of civilization the countries, young or old, whose energies have not yet been sapped by the seductions of the policy of least effort.

The great sacrifices of her pilots have earned for her first place in the great competition which is coming; let France understand and let her not be outdistanced!



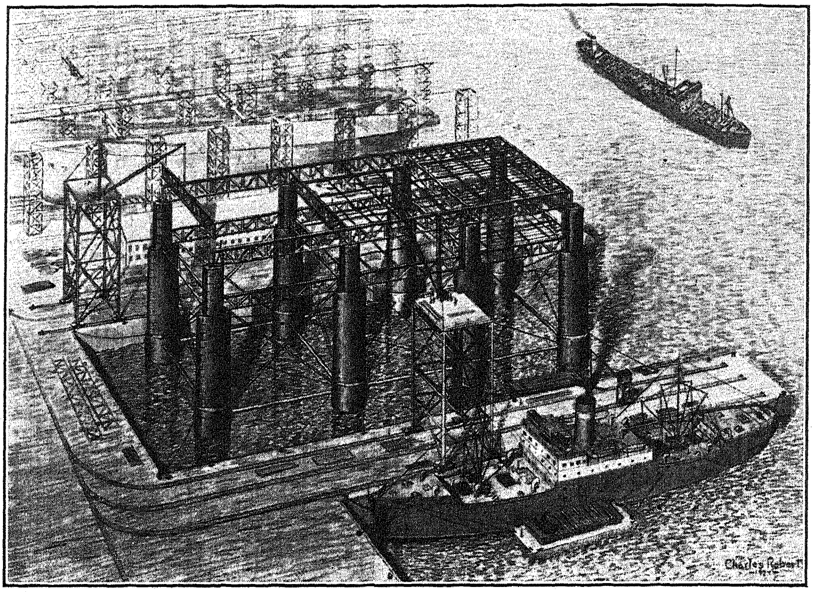
1. PROPOSED FACILITIES FOR THE NORTH ATLANTIC.

The circles represent the islands which form landing places; the dotted circles, intermediate islands. The average distance between these islands is about 600 miles.



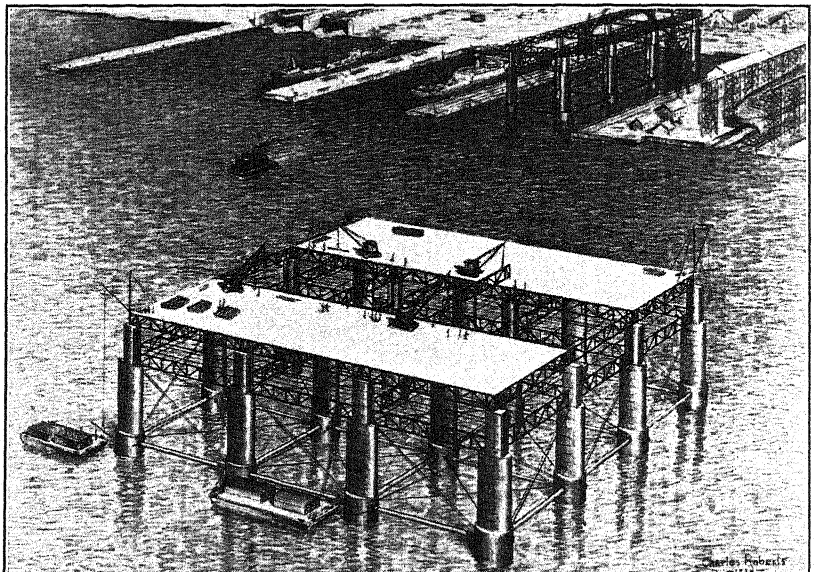
2. A TRIAL MODEL.

This model, on 1/32 scale, gave results conforming to predictions.



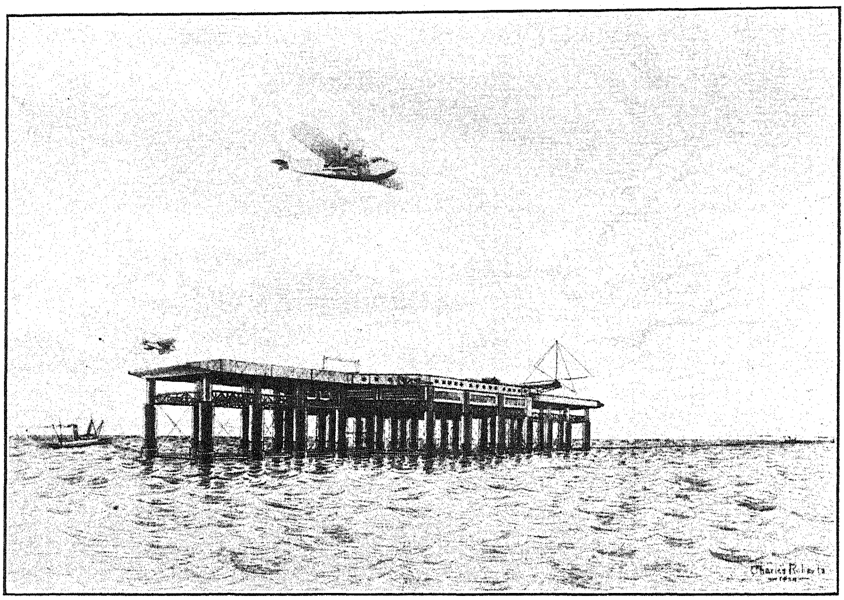
1. ARMSTRONG SEADROME.

Erection of central port section of seadrome in wet basin of shipyard. Section 134 feet wide by 410 feet long over all. Depth of water required for erection, 28 feet.



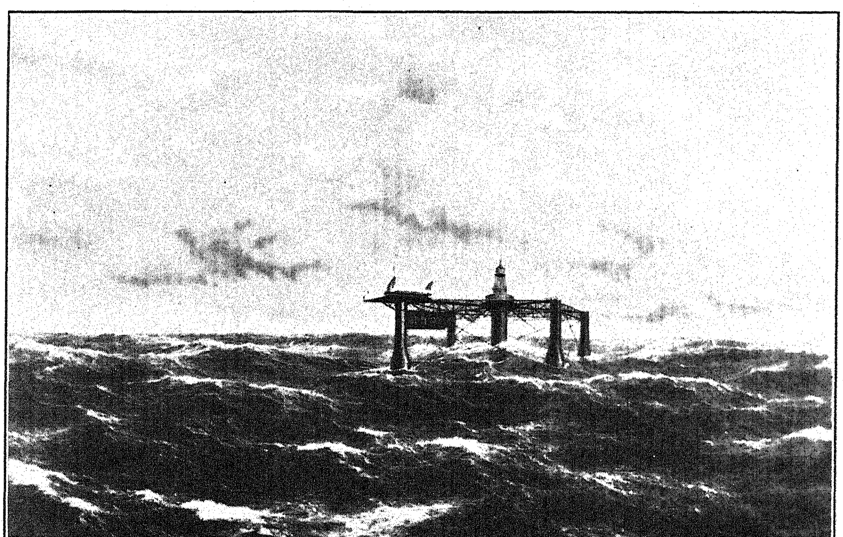
2. ARMSTRONG SEADROME.

Assembly of two central sections off shipyard. (Note end section being erected in background.) Assembled sections 334 feet wide by 410 feet long over all. Draft 34 feet with all decks in place. Four assembled sections complete seadrome. About 26,000 tons of steel and iron is required for one seadrome.



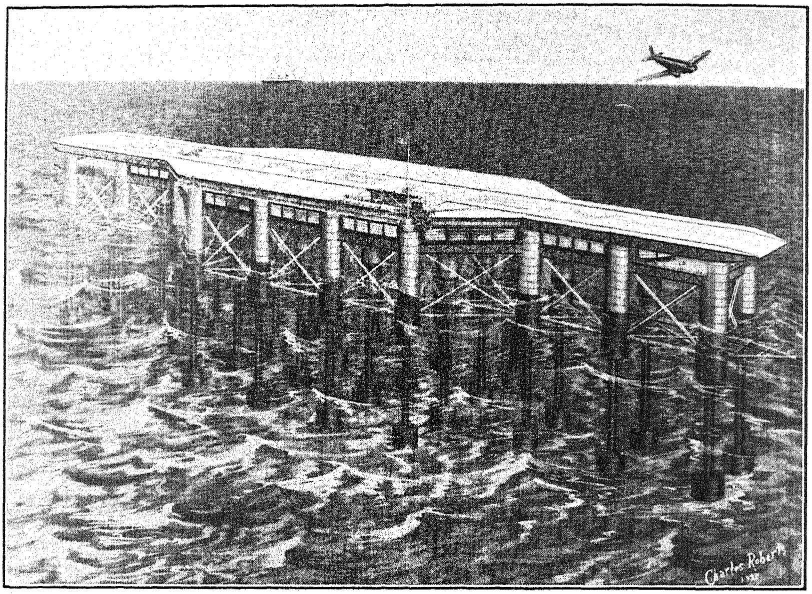
1. ARMSTRONG SEADROME.

Completed seadrome with all equipment installed being towed to sea to anchorage site. Structure in shallow draft condition. The draft in the open ocean will be increased to about 50 feet to give maximum stability. At towing draft, the deck will be 130 feet above the water line. Light draft displacement approximately 40,000 tons. The towing tugs will be assisted by the four propellers of the seadrome totaling 2,000 horsepower.



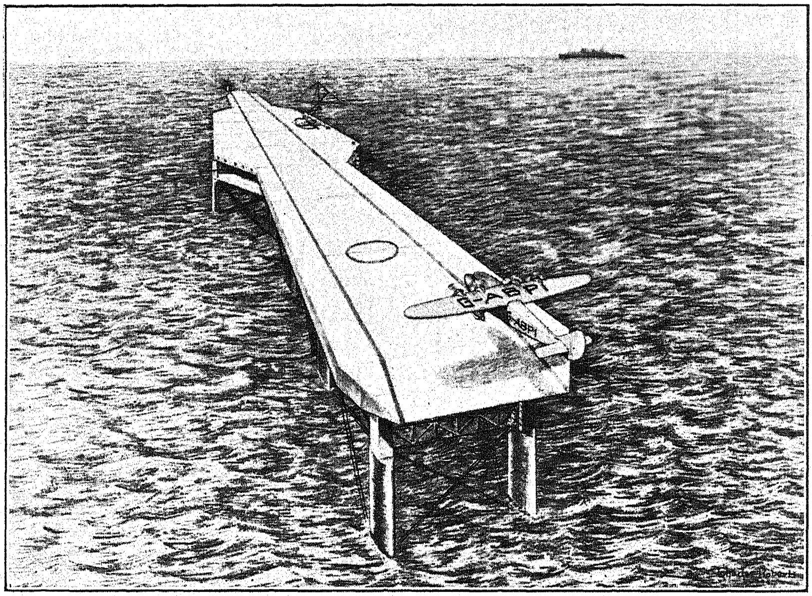
2. ARMSTRONG SEADROME.

Beacon station anchored on ocean air route, equipped to give rescue service, radio direction, and weather information. Length 218 feet, width 112 feet, draft on service duty 180 feet, towing or light draft 26 feet. Displacement when anchored on service duty 2,460 tons.



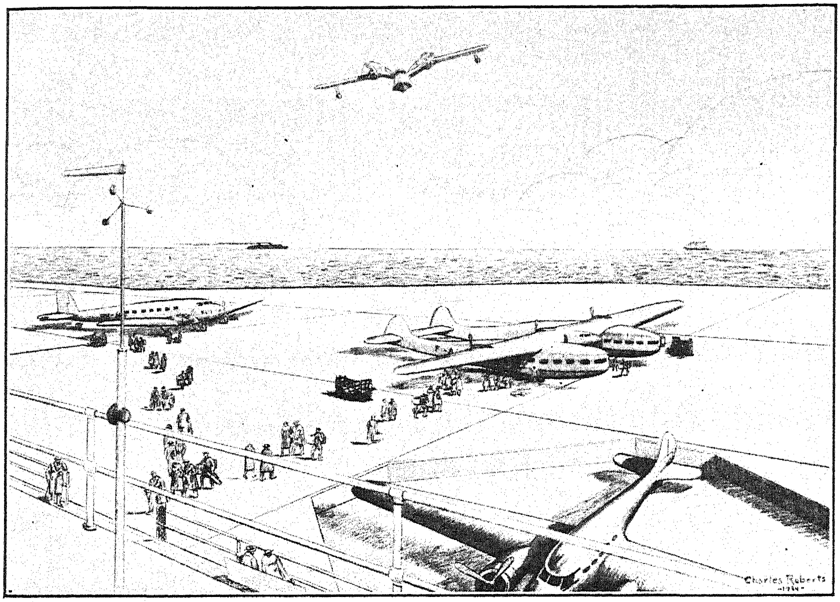
1. ARMSTRONG SEADROME.

A perspective view of a seadrome on service duty showing immersed portion as well as that above the water. The elevator for taking planes from the landing deck to the hanger deck below is shown.



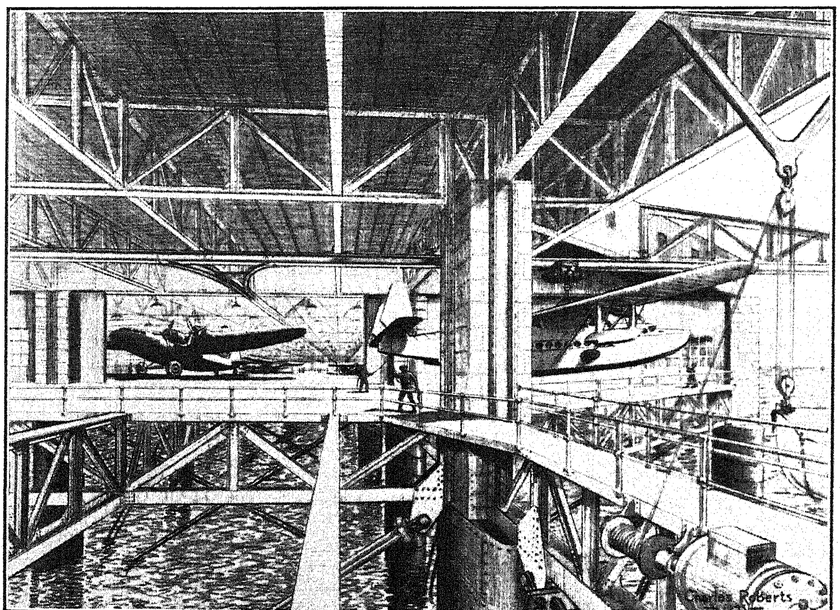
2. ARMSTRONG SEADROME.

Completed seadrome anchored on ocean airway. Landing deck 1,500 feet long, width at center 300 feet, at ends 150 feet. Deck 100 feet above sea level. Draft 210 feet. Total displacement on service duty 65,000 tons.



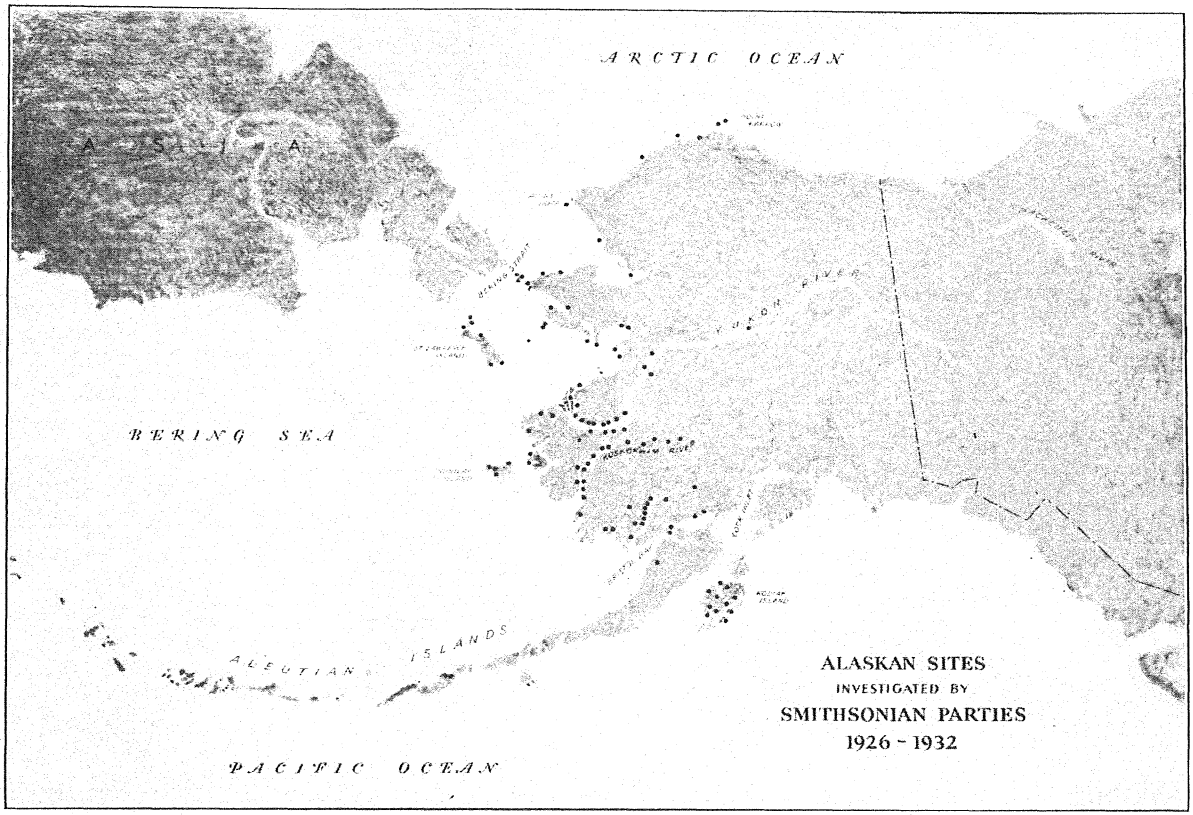
1. ARMSTRONG SEADROME.

Deck scene at seadrome no. 4 of the trans-Atlantic series. A junction point for traffic from Mediterranean ports and the Far East. Note plane elevator in foreground and coastal patrol flying boat overhead. Proposed Blériot airplane in foreground.



2. ARMSTRONG SEADROME.

Lower deck, containing hangars, repair shops, dwelling quarters for the crew, and hotel accommodations for passengers.



MAP OF ALASKA, BERING SEA AND THE PROXIMATE PARTS OF ASIA.

Dots show the most important old sites located or examined by the Smithsonian expeditions. Since 1932 work has been restricted in the main, to Kodiak Island.

THE COMING OF MAN FROM ASIA IN THE LIGHT OF RECENT DISCOVERIES [1]

By Aleš Hrdlička
United States National Museum

[With 1 plate]

The chief deduction of American anthropology, in the substance of which all serious students concur, is that this continent was peopled essentially from northeastern Asia. The deduction is based on the facts that man could not have originated in the New World, and hence must have come from the Old; that the American aborigines are throughout of one fundamental race, the nearest relatives of which exist to this day over wide parts of northern and eastern Asia; and that the only practicable route for man in such a cultural stage as he must have been in at the time of his first coming to America was that between northeastern Asia and Alaska.

The principle of the problem being thus settled, there remained the important details of when and just how man came to America; what he brought with him in the way of language, culture, and physique; how he proceeded in peopling the new continent after he had reached it; and what were the genetic relations of the Eskimo and the Indian.

On all these large questions new light has been shed by recent explorations in the far Northwest under the auspices of the Smithsonian Institution. Initiated by the author in 1926, these explorations have now been carried on in Alaska for 9 years, and in some years by two separate parties. They comprise systematic work both in physical anthropology and in archeology and have reached over nearly the whole of the western coasts, from Point Barrow to Kodiak Island, and over the principal islands of Bering Sea. They resulted in the location of a large number of old sites of habitation, in the collection of valuable skeletal materials from the entire region, in the obtaining of anthropometric data on the full-blood remnants of the living populations, and in the unearthing of unsuspected rich

[1] Reprinted with revisions (bringing article up to date) by permission from the Proceedings of the American Philosophical Society, vol. 71, no. 6, 1932.

old cultures about Bering Strait, on St. Lawrence Island, on the lower east coast of Bering Sea, and on Kodiak Island.

Thus, what until recently has been but a trail of theories through a jungle of possibilities is gradually becoming a broad road paved with substantial facts and determinations. The work is far from being finished, but it will not be long before the main questions at issue will have been answered. It may be well to state at once, however, that the evidence will not be of a simple nature, for wherever it has been possible to approach matters more closely they have invariably grown in complexity. Furthermore, it is also becoming plain that much of the desired direct evidence on human movements in the far North will probably never be uncovered.

Before discussing the results, it may be helpful, with the aid of the accompanying map, to give a few details about the explorations on which they are based.

They are to date briefly as follows:

1926. Survey of the middle and lower Yukon River, upper Bering Sea, and the coasts to Point Barrow, by A. Hrdlička.

1927. Continuation of the work along the west coast from Bristol Bay to the Yukon, with particular attention to Nunivak Island, by Henry B. Collins, Jr., and T. Dale Stewart.

1928. Excavations on the Punuk and St. Lawrence Islands, with collecting along the Seward Peninsula, by Collins.

1929. Anthropometric and archeological work along 1,500 miles of the Yukon, by Hrdlička, aided by J. Maly. Excavations at St. Lawrence Island, Point Hope, and other places, by Collins.

1930. Anthropometric and archeological work along the Kuskokwim, by Hrdlička. Excavations at St. Lawrence Island, by Collins.

1931. Anthropometry and archeology of the Nushagak River and its tributaries, of the proximate parts of the Alaskan Peninsula, and on Kodiak Island, by Hrdlička. Archeological work in the upper Bering Sea and the Arctic, by J. A. Ford and M. B. Chambers.

1932. Excavations on Kodiak Island, archeological survey of the island, anthropometric study of the few surviving full bloods, by Hrdlička.

1934. Excavations on Kodiak Island, survey of parts of Cook Inlet and northern coast of Shelikov Strait, by Hrdlička.

1935. Excavations on Kodiak Island, survey of Takli Island, by Hrdlička.

The preliminary accounts of the work were published in the Smithsonian exploration pamphlets for the respective years. More complete reports are the writer's Anthropological Survey of Alaska (46th Ann. Rep. Bur. Amer. Ethnol., 1930) and Collins' Prehistoric Art of the Alaskan Eskimo (Smithsonian Misc. Coll., vol. 81, no. 14, 1929), with his Archeology of the Bering Sea Region (Smithsonian Rep. for 1933). The main parts of the collections and data are still under elaboration, and many years must elapse before the results can be fully given. But the essentials which these researches elucidate have already assumed a more or less substantial form, and they may briefly be summarized as follows:

The Bering Sea islands (barring the Pribilofs), the western coasts of Alaska, the lower courses of the western Alaskan rivers, the Peninsula and the Aleutian, Kodiak, as well as other southwestern Alaskan islands, are all rich in " dead " sites or villages. These may be found at the mouth of every larger fresh-water stream and in other favorable locations. Many of the sites were relatively small, the settlement having consisted of but a few dwellings, but some were rather large, with a population that reached well into the hundreds. The large majority have gone " dead " since the Russian times, generally through epidemics, and show no material age. But there are some in which the house refuse reaches very considerable proportions, in instances as much as 15 to 20 feet in depth, and in which signs of the white men's contact are either wholly absent or but superficial; such sites must go back for many centuries.

Nothing whatever has been discovered so far, however, that would indicate any great antiquity. The total of the human remains that have become known to this day can undoubtedly be encompassed within what would correspond to the Christian Era, and mostly within the last half of it; and there has appeared to date nothing that would give hope of much earlier discoveries. In reality, the more the conditions in these regions are studied the fainter becomes the hope of ever finding anything more ancient, unless this be through some rare accidental discovery. The fact is that over most of the regions involved the ground on which human remains are now found is of more or less recent formation, and that older places on which man may once have been settled have been washed away, or so covered with silts or loess and jungle that to locate the remains is now impossible.

The Bering Sea region as well as the coasts to the north of it are geologically alive, constantly cutting and building. The present coasts, the mouths of streams, the platforms suitable for man's habitation, with rare exceptions, were not there 500 years ago, and 1,000 or 2,000 years ago the whole map of these parts was different. Within the memory of living man whole sloughs (side streams) have been silted up and wooded, whole bluffs or villages with burial grounds cut away, while new channels, bars, islands, and dunes have been built. Not even the rocky banks and coasts have been spared the attrition by frost, wind, wave, and current. It is now only too evident that all expectation of finding in Alaska, through systematic work, the remains of the early migrants to America across Alaska must practically be abandoned. This is our main negative conclusion.

But there is also much on the other side of the scale.

Examination on the spot of the Bering Strait region shows plainly that, once man arrived in northeasternmost Asia, the passing over to the visible American side was not merely possible but inevitable. The simultaneous conclusion is that not only was no land connection

needed for such a passage but that had the same existed man would not have used it; he would have followed the much easier route over the water.

The next major point that looms up conclusively is that the coming of man over from Asia to America could never have been in the nature of a single or large migration. Rude and barren as is the American territory nearest Asia, that on the Asiatic side is even ruder and colder and stormier, and as such it could never have accommodated any large population. There could have been, therefore, but a few people passing over at any time. These might have influenced the rest of their clan or group, but after that an interval would necessarily elapse before a new lot would reach the northeasternmost parts of Asia, from which it in turn could come to America. There could, therefore, never have been any large or continued migration into America, but only relatively small and interrupted dribblings over, but dribblings that went on over several millennia.

Such parties as came must have been parties of people well acquainted with and provided for coastal navigation, for their movements as well as their main livelihood in Asia depended on such navigation. They doubtless had small individual, as well as large, or group, skin boats, the latter probably with a skin sail,[2] in which they could readily cross over. All this is shown by the inhabitants of the same region today, who in their skin boats cross over the strait whenever they need to without much difficulty; only now they have to return, for the American side is already peopled.

The further problem was as to the movements of the newcomers after they reached the American side.

To one viewing the map of western Alaska it would seem most natural that people coming from Asia would soon reach the delta of the Yukon, through this funnel pass into the interior, and from there to Canada, southern Alaska, and the rest of America. The actual examination of the Yukon, which is, indeed, a great artery, does not sustain this view. The river is 2,700 miles long. It has a swift current, its waters are often rough, and both it and its tributaries ascend toward very rugged, icy mountains, besides which its valley is so plagued during the summer with mosquitoes, gnats, and horseflies that all larger game leaves for the highlands. It was not impassable, and had doubtless been tried again and again, but that the peopling of America proceeded through its trough is neither probable nor supported by any evidence thus far discovered.

It appears much more likely that such moderate groups of fishermen and sea hunters as reached America, finding no one in the way,

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[2] One such native "umiak-pak" (large boat) with a square sail made of seal skin was seen by the writer near the Bering Strait as late as 1926.

proceeded with but short stops toward the "sun", that is southward, skirting the inhospitable coasts until they reached the Peninsula. This, we now know, they found to be a regular sieve of passes with easy portages, and once over these the newcomers were in the Alaskan Gulf, or in Cook Inlet, with the road to the east and the northwest coast relatively easy. This was a much shorter and much less difficult route than that up the Yukon would have been, and brought the Asiatic man much sooner to regions that offered him inducements for a more permanent habitation. The oldest habitations of that nature were, therefore, in all probability in or along the old Alaskan coast of Bering Sea and are not to be expected in other parts of Alaska; and, as the old coasts are gone, such sites should rather be looked for in the favorable spots of the western coasts of southern British Columbia and in Oregon, Washington, and California. The lower Frazier and Columbia River Basins and parts of California would seem especially propitious.

The next large questions on which our explorations have already shed much light are those of what the Asiatic migrants brought with them to America in the way of language, physique, and culture.

As to both language and physique, it may safely be assumed that if there were repeated comings of man, which view we have seen to be the most justified one, then there surely came also differences in language and physique, for no two ethnic or even tribal groups are identical in these respects. Of the fact that different physical types came in, we have already found sufficient evidence in the skeletal remains recovered from the Bering Sea and adjacent regions, as well as elsewhere in America.

As to languages, much can now be discerned which formerly was obscure. The former general opinion was that the many varieties of languages and dialects found in the two Americas were in general of American development, and this argument had repeatedly been used in support of a great antiquity of man on this continent. This was, it is felt today, a superficial and unnatural assumption. The probability, in view of the present light, is that a series of languages and dialects, rather than one language, were brought over from Asia, to differentiate here and diverge further under the influences of time, isolation, and other factors. Unless it is accepted that there was but a single coming of man to America, and that by one homogeneous group, the notion of the advent of but a single original language from Asia is impossible.

The evidence of the skeletal remains, as well as that of the living, has a direct bearing on the problem of the physical differences in the newcomers. There are found in the two Americas at least five or

six fairly distinct physical types of the Indian. These types naturally must have developed somewhere, and this may as well have been in America as elsewhere; but their characteristics, distribution, and stability all speak for an old differentiation, which, in some cases at least, must have been, it seems, pre-American. The remains in Alaska, nearest the source, show no such homogeneity as would accord with the conception of a unique original type. From the point of view of physical anthropology we are steadily becoming more convinced that the comers from Asia, though all of one large human stem, the yellow-brown, brought with them already considerable physical heterogeneity; and if this is true of physical characteristics, it is certainly true also of languages and culture. These are no speculations or theories but results of clearer insight into these matters arising from the results of the late explorations and accumulating materials.

These explorations shed also a direct and remarkable light on the question of what the Asiatic man brought with him culturally.

Up to very recently there prevailed among American scholars the notion that the American cultures were of essentially or even wholly American development. This would imply that the comers from Asia brought with them but a sort of undifferentiated simple culture on the basis of which the American developments took place; or that if they brought any specializations, these were forgotten under the new environment. The answers to this from our excavations are that the farthest Northwest, in as far as we can reach, is culturally rich and varied; that the oldest of the cultures there discovered, namely, the fossil-ivory culture of northern Bering Sea and of the northeastern Asiatic coasts, and the old culture of Kodiak Island, are not only the richest in forms that are the most beautiful as well as conventionalized, but that they come in full-fledged and that their outstanding features may be followed deep into the American Continent; while other cultural evidences are appearing that connect directly on one hand with the neolithic attainments of Asia and on the other hand with numerous elements in the cultures of the northwest coast and farther southward, in the Southwest, Mexico, and even Central South America. These are no introductions into Alaska from the American side, for the oldest and best antedate the continental differentiations. They evidently appear initially in the north and were brought from Asia, where they must have had a long period of development. The cultural evidence of the late explorations shows, therefore, that the men from Asia were coming over not as a people without a culture, but already as carriers of well-advanced cultures of, in substance, the American type, and from which further Ameri-

can developments, according to differing needs and opportunities, could readily have taken place in different locations.

As to the Old World ancestry of the American Indian it is ever more strongly indicated by the accumulating evidence that this connects with the earlier neolithic man of Asia and through him with the Magdalenian and Aurignacian man of northern Asia and Europe.

A word, finally, as to the present aspects of the problem of the genetic relations of the Eskimo to the Indian. The Eskimo appears to be a later offshoot from the same old stock that gave us the Indian. He came later and in two subtypes, one nearer to, the other farther from, the Indian. The relation of the Indian and the Eskimo may best perhaps be represented by a hand with outstretched fingers. The diverging fingers are the different types of the Indian: the thumb, which should be double, represents the Eskimo. The thumb is farther apart but originates from the same hand, which is the old or paleo-Asiatic yellow-brown strain, a strain that gave us the ancestry of all the aboriginal Americans.

The Smithsonian explorations in the far Northwest will continue. There is ahead still an enormous amount of labor. But the "principles" of the region are already appearing, and they promise to place, before long, many of our problems of American origins on a firm scientific foundation.

SUMMARY

Since 1926 the Smithsonian Institution has carried on renewed explorations and studies in Alaska relative to the origin of the American aborigines.

These explorations, partly somatological and partly archeological, have thrown new and important light on the problems of the coming of man from Asia.

The main indications are that man came over very gradually and disconnectedly over a long period of time; that he brought with him differences in type, language, and culture; that at least some of the culture he carried was already far advanced; that according to all indications he did not proceed to people America across the mainland, but by skirting the western and southern coasts of Alaska; and that the Eskimo, the last comer, in his two types is a blood relation of the Indian.

The material evidences of the early comers may never be recovered in western Alaska, which has suffered important geotechnic changes since man's arrival, and where, moreover, most of the ground, with its contents, is perpetually frozen. There is more hope along the Gulf, but especially along the western coasts of the continent, from British Columbia to California and Mexico.

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THE ANTIQUITY OF MAN IN AMERICA IN THE LIGHT OF ARCHEOLOGY[1]

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INTRODUCTORY

The American aborigines have been the special object of interest to students of early man now for more than 400 years. During this interval, paradoxically enough, not only have the inherent problems increased in number rather than diminished, but the point of view or angle of attack has shifted from time to time. On the whole, however, these shiftings have conformed to the developmental course of science in general; that is, they have tended from the more obvious to the less, from the abstract to the concrete—in short, from the essentially speculative to the distinctly empirical approach.

At first, and for a long time, the question of origin held exclusive attention. Who was the Indian or whence did he come? The answers, contributed largely and of necessity by armchair students, have been many and amusingly varied, but the final reply still awaits the recovery of substantial archeological facts and need not, therefore, concern us much in this essay. By the middle of last century the more specific question of antiquity took precedence. How long had the Indian been in America? A wide range of contradictory and more or less startling replies have been furnished, for the most part by paleontological discoveries, and these it is proposed to sum up and to contrast in character and reliability with the available archeological data. Finally, some three or four decades ago, there came to the front the still more specific question of cultural development. What has been the Indian's history since he came here? This is a distinctly archeological problem, one that can be settled only by painstaking search for the fragmentary relics scattered over the entire New World and by a rigid comparison of

[1] Reprinted by permission from The American Aborigines, Their Origin and Antiquity, a collection of papers by 10 authors, assembled and edited by Diamond Jenness and published as a Presentation Volume, on the occasion of the Fifth Pacific Congress, University of Toronto Press, Victoria, Canada, 1933.

the resulting record with the similar record of the Old World. Naturally the time has not arrived for final conclusions; but enough facts are available already for what it is hoped may be a helpful preliminary statement. To this end it is the purpose here to sketch briefly the historical development of the problems involved, to present a summary of the evidence already at hand, and to draw such conclusions as seem warranted.

HISTORICAL DEVELOPMENT OF PROBLEM

THE PROBLEM OF ORIGIN

As has been intimated, the first question which arose with respect to the American Indian concerned his identity or origin. It seems a natural enough question and the only one which at the time could be considered speculatively—that is, without waiting for the tedious accumulation of additional facts. But there was a specific reason why this question arose when it did; and because this early formulation of our problem, with its lengthy treatment, throws a revealing sidelight on the workings of the human mind, brief consideration seems irresistible.

To the pagan and unschooled Norsemen of the year 1000 the trans-Atlantic savages appear to have presented no particular historical problems. To the more sophisticated Columbus of 1492—however puzzled he may have been—these same or similar savages were obviously and necessarily Asiatics or, more precisely, Indians. But this semiempirical view of the great navigator suffered sudden and long eclipse at the hands of medieval scholarship, whose opportunity came in 1513 when Balboa discovered the Pacific Ocean and thereby appeared to demonstrate that the continent reached by Columbus was a New World, and its inhabitants likewise new and in no way accounted for by the ancient authoritative books handed down. The first result was that while the New World with its gold and other riches was accepted as reality, the truly human nature of its inhabitants was temporarily held in doubt. But, gradually, there arose a long succession of more or less speculative attempts to link the New World people with one or another of the Old World nations and to account for their presence in America by migrations, necessarily in relatively recent or so-called "historic times." Needless to state, several of these argumentative demonstrations still have their adherents, and the latest of them—a modernized version of an old theory—traces all that is worth while in native American physique and culture to Egypt.

Parenthetically, this attitude of mind and general course of thought development may be readily enough understood when we recall that European scholars were steeped in ancient history and

tradition, which divided the known world into three parts—Europe, Asia, and Africa—and recognized only three corresponding great racial groups of mankind, the descendants, respectively, of Shem, Ham, and Japhet. With the psychologically fascinating speculations flowing largely from these premises concerning Indian origins we are not now directly concerned; but it is only tardy justice to Columbus to state that the latest consensus of scientific opinion tends to vindicate his practical judgment as to the Asiatic affinities of the American Indians.

THE PROBLEM OF ANTIQUITY

The question concerning the length of time the Indian had resided in America could scarcely have been formulated as a distinct or vital topic until after the year 1858, when the truly geologic antiquity of mankind in general was finally admitted by European scientists. To be sure, already a full century before that date reports had been published, for example by Peter Kalm,[2] of early eighteenth-century archeological discoveries in New Jersey which hinted strongly of Quaternary age, but neither these nor the similar and better authenticated finds in Europe at about the same date (1700) received serious attention. As late as 1835–44, a Danish naturalist[3] discovered in six separate Brazilian caves near Lagoa Santa no less than 30 human skulls and skeletons, as well as traces of artifacts in apparent association with the bones of living and extinct animals; but as he himself was not entirely convinced of the contemporaneity of his associated finds, the occurrence appears to have excited no particular attention. Even the numerous alleged implemental and skeletal finds in the Tertiary gold-bearing gravels of California during the 1850's passed unnoticed. The time was not ripe for frank consideration, except by a few isolated investigators. However convincing such discoveries appeared to the common man, who presumably did not perceive their full implication, the medieval scholars could not entertain their reality, and the foremost among the scientifically minded, like Cuvier, hesitated in spite of the accumulating evidence and resorted to every kind of explanation except the obvious one.

Parenthetically again, we may pause briefly to consider the dilemma in which the men of learning, who relied implicitly on the received ancient authorities, found themselves. Pagan classical authors, it is true, had written vaguely about the early use of stone implements, but Hebrew tradition was silent on the subject. If,

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[2] Kalm, Peter, Travels into North America, 2d ed., vol. 1, pp. 277–280, London, 1772.

[3] Lund, P. W., Blik paa, Brasiliens Dyreverden, *etc.*, Kong. Dansk. Vid. Selsk. Nat. Math. Afh., Niende Deel, pp. 195–6, Kjöbenhavn, 1842. For English digest of Lund's views see A. Hrdlička, Early man in South America, Bull. 52, Bur. Amer. Ethnol., pp. 153–65, 1912.

therefore, the reality of a past stone age was demonstrated in 1836 for northern Europe, and if the inhabitants of America and other parts of the newly discovered world were carrying on practically without the use or knowledge of metals, the facts could be explained only as the results of degeneration from the original advanced state of culture indicated in the Book of Genesis. As for a prehistoric period of human existence, reaching back into earlier geologic times, that was clearly impossible; and when discoveries were made which demonstrated Quaternary age, such as human relics associated with extinct animal remains laid down in caves or in river deposits, the occurrences were finally explained as the obvious results of the Noahic flood. But, as stated, the old theory of origin by creation, barely 6,000 years ago, at last gave way before the accumulated facts which it could not explain; and, in accordance with the new evolutionary conception of life and culture, search for evidences bearing on the extended prehistoric antiquity of man became almost at once world-wide.

The immediate outcome of this newly acquired freedom of inquiry and of interpretation was in some respects disastrous, both in Europe and in America. In Europe, inside of a decade, crude flints resembling artifacts, and as such called "eoliths", were uncovered which it was thought proved the reality not only of Quaternary man but of a very much earlier tool-using being. At the present time such puzzling evidence has been recovered from even the Eocene formations—that is, from the very beginning of Tertiary times, when mammalian creatures were only just coming into being. The result is, naturally, a division of opinion and occasional violent controversy.

In America the apparent course of progress has been still more startling. Inspired and instructed by European discoveries, our enthusiastic students, professional and amateur, began shortly to search for relics either of the same type or of equal antiquity, and, as might be expected, soon found both kinds of evidence. With respect to antiquity Prof. J. D. Whitney, State geologist of California, led the van. Stimulated perhaps by the alleged discovery of the famous Calaveras skull in 1866, he began that year to investigate the many and seemingly well-founded current rumors of hundreds of archeological finds made by gold miners during the preceding decade deep in the gravels of the Sierra Nevada slopes, and in 1879 concluded a fairly exhaustive report by declaring his belief in the reality of Pliocene, if not actually Miocene, man in California. At about the same time Middle America [4] supplied a num-

[4] Whitney, J. D., Auriferous gravels of the Sierra Nevada of California, Contributions to American Geology, vol. 1, Mem. Mus. Comp. Zöol., pp. 288–321, Cambridge, 1880.

ber of suggestive finds, which, however, have never been verified.[5] South American investigators were not far behind, and in the person of Florentino Ameghino, director of the Natural History Museum of Buenos Aires, showed even greater zeal and courage in relation to human antiquity. Beginning about 1870, this able paleontologist made known a long series of discoveries, somatic and cultural, from the local Pampean and earlier formations, which were held to prove the long contemporaneity of man and of various extinct animal species in Argentina. He dated some of these archeological discoveries clear back to Eocene times, and ended by claiming that the world's mammalian fauna, including man and his forerunners, had originated in South America.[6]

THE PROBLEM OF CULTURAL DEVELOPMENT

Up to this time the investigations had stressed the antiquity rather than the typology or characteristics of the archeological objects discovered; but during this same eighth decade of last century men with little or no paleontological experience, but correspondingly more familiar with cultural data, came forward. As early as 1872, Dr. C. C. Abbott announced his discovery of implements of Paleolithic type in both the supposed early postglacial and the underlying glacial deposits on the east bank of the Delaware River, immediately below Trenton, N. J.[7] This double-count claim was defended with increasing vigor by its discoverer for nearly 40 years and gained several adherents among the leading scientists, such as Prof. Marcellin Boule, of Paris, and Prof. F. W. Putnam, of Harvard University; yet although independently investigated time and again, its full significance has never been satisfactorily determined.

In the course of the following decade other champions of early man in America appeared, the most radical being Curator Thomas Wilson, of the National Museum in Washington, D. C., who ventured to offer a demonstration of the presence of the Paleolithic industry on purely typological grounds.[8] Mr. Wilson, incidental to extended residence in Europe, had obtained first-hand acquaintance with the stone implements typical of the Lower Paleolithic, in particular the so-called "coup-de-poing" or hand ax, and on returning to America he immediately proceeded to look for similar implements here. The

[5] See E. G. Tarayre (and E. T. Hamy), Arch. Comm. Sci. Mexique, vol. 2, pp. 6, 7, 409, etc., Paris, 1884.

[6] I am not familiar with all of Ameghino's original papers, but a summary of part of the evidence is supplied by Outes and Bruch in a book entitled "Los Aborigines de la Republica Argentina", Buenos Aires, 1910. For a good English summary, see M. Boule's Fossil men, pp. 413–37, Edinburgh, 1923; also Hrdlička, op. cit.

[7] Abbott, C. C., The Stone Age in New Jersey, Amer. Nat., vol. 6, 1872; Primitive industry, Salem, 1881; Ten years digging in Lenape Land, Trenton, 1912.

[8] Rep. U. S. Nat. Mus., 1887–8, pp. 677–702, 1890.

national collections at once yielded him several hundred likely objects, many of them actually labeled "Rude and unfinished implements of the Paleolithic Type" and derived from practically all sections of the United States, including a few from the environs of Washington itself. Private collectors supplied many more specimens, gathered principally from the hills in and around the Capital City; and a personal visit to the local sites thus indicated revealed these rude "implements" in great profusion and added a round 300 items to his series, making a total of 745 for the District of Columbia alone and a grand total for the country of about 1,400 specimens. Highly gratified, Curator Wilson's comparative studies next emboldened him to state that our American coups-de-poing were not only similar to those of Europe but identical with them in both form and purpose. On the strength of these observations he sent out in 1888, under the auspices of the Smithsonian Institution, an illustrated circular calling for additional information. It came quickly in the shape of 209 replies, 33 of them accompanied by actual specimens. As a result, a table was published in the cited report which purports to demonstrate the existence of Paleolithic implements in 35 of the United States and Territories, as well as in the adjacent Canadian Province of Ontario, and which places the number of specimens then available in the National Museum at 1,739 and the total reported upon at the grand figure of 8,501.

Meanwhile, during this same ninth decade, conservative as well as critical students made their timely appearance. Among the first the most formidable, or at least the best informed, was Prof. H. W. Haynes, of Boston. Like Wilson, he was conversant with the details of European archeological investigations, claimed to have discovered the first known paleoliths in Egypt, and was the possessor of personally made prehistoric collections from various parts of the eastern United States. On the basis of his study of these latter data he expressed himself as convinced that our rude American implements occurred in isolation and that they were not of Indian origin; but at the same time he was not prepared to vouch for their true Paleolithic character and still less for their geologic antiquity.[9]

The real opposition was led by Prof. W. H. Holmes, of the Bureau of American Ethnology in Washington, D. C., who, according to personal communications, stepped into his role of critic in the late eighties as a direct result of the claims made by Thomas Wilson and F. W. Putnam. In the course of the next 10 years he patiently investigated, or reinvestigated, not only the District of Columbia sites but many other more famous localities throughout the country, including

[9] Proc. Boston Soc. Nat. Hist., vol. 21, p. 382, 1882. See also Haynes and others in Justin Winsor's Narrative and critical history of America, vol. 1, part 2, pp. 329–412.

Trenton, N. J., and the gold-bearing gravel sites of California; and as a result he "challenged the whole body of American paleolithic 'evidence'" and at the same time the evidence for geologic antiquity. The Californian claims were, with one exception, disposed of as either accidental inclusions or frauds,[10] while the District of Columbia sites were demonstrated to be quarry and workshop locations and their numerous so-called "paleoliths" to be nothing more than blanks (unfinished implements) and rejects.[11]

This all too brief sketch brings the development of American prehistoric investigations down to the beginning of the present century and within the memory of many of those actively at work in anthropology, so that little more need be said historically. For a time interest in the antiquity problem as such languished somewhat. Our steadily increasing number of archeologists busied themselves at first with the accumulation and study of data, leading to a tentative determination of culture areas and later to systematic excavations resulting in more or less definite chronologies for several of these areas. But meanwhile discoveries and arguments bearing directly or indirectly on the question of antiquity have not been wanting, especially during the last few years. Indeed, at the moment of writing (1931), all three aspects of the American Indian problem—origin, antiquity, and cultural development—are well to the front, and we may properly turn to a summary presentation of the accumulated evidence.

TYPES OF EVIDENCE AVAILABLE

The claims brought forward as having a bearing on the antiquity of man in America cover a wider range of phenomena, which for purposes of treatment it is necessary to group in some fashion. As evidence, some of the alleged facts are merely circumstantial; others are, in part, at least more than doubtful; still others are positive; and lastly, some are negative. It is not the writer's ambition, however, to pose as judge until necessary, and accordingly the attempt will be made to present the various types of data under headings corresponding as far as possible to their respective spheres of origin—ethnological, paleontological, and archeological.

ETHNOLOGICAL INDICATIONS

For some time past, as knowledge of our living tribes has accumulated, a number of ethnologists have expressed themselves as convinced of man's geologic antiquity in America on the grounds largely of what

[10] Holmes, W. H., Review of the evidence relating to auriferous Gravel Man in California, Smithsonian Rep. 1899; Pitfalls of the Palæolithic theory in America, Proc. 20th Int. Congr. Americanists, pp. 171–75, 1922.

[11] Holmes, W. H. Stone implements of the Potomac-Chesapeake tidewater province, 15th Ann. Rep. Bur. Amer. Ethnol., 1897.

he has accomplished, or stated more broadly, on the great variety of cultural and somatic phenomena presented by the continent. Some of these expressions, to be sure, were prompted by suggestive paleontological discoveries, like those at Vero and Melbourne in Florida, since 1915; but none, so far as known, have covered the various aspects of the subject sufficiently to warrant citation. Selecting, therefore, from scattered written sources, as well as from current ideas, and adding such personal views as seem justifiable, the ethnological argument may be presented in bare outline under the recognized anthropological categories of bodily physique, language, social organization, and material culture.

Under the caption of "material culture" it should be pointed out that the New World, with the exception of Iceland and possibly Greenland, when first discovered, was found populated from one end to the other; the inhabitants were acclimatized from the Arctic and near-Antarctic to the Tropics, from sea level to the highest habitable altitudes; they had been in residence long enough to have arrived at notions of tribal boundaries and to have acquired extensive knowledge of their distinctive habitats as to flora, fauna, and mineral resources; indeed, so complete was the adjustment between the aborigines and their widely differing types of environment—littoral, jungle, woodland, plain, desert, elevated plateau, and mountain fastness—that it had produced no less than 23 distinguishable archeological culture centers, some of them of such complexity and strength that they are still functioning. In the interval, also, various arts and industries were developed, some of them—as for example irrigation, metallurgy, architecture, sculpture, ceramics, and textiles—to very high degrees of excellence; numerous wild plants were brought under cultivation and practically all the suitable native animals domesticated; and as proof of all these labors there were produced and left behind impressive ruins, earthworks, and accumulations of refuse, as well as minor artifact remains of stone, bone, shell, and metal, in number and quantity beyond present estimation. Not least important in this connection are the indications that most of this remarkable development was independent of Old World influences.

Concerning the aspect of social organization as developed in America, whether political or religious, the writer hesitates to offer characterizations, being insufficiently familiar with the real nature of the facts called for. The number and variety of phenomena are obvious enough, however. Ethnologists have distinguished in the New World no less than 368 major tribal groups with countless subdivisions; but just what relation, if any, these entities bear to

the linguistic and somatic classifications is not clear. It is a matter of common knowledge, however, that group control, both temporal and spiritual—if separable—varied from the simplest imaginable to the highly complicated, from a barely recognized leader or chief to hierarchical authority, with corresponding states of organization ranging from practical anarchy among the Eskimo through such intertribal affiliations as the League of the Iroquois in northeastern North America and the military theocracies in Middle America to something like communistic despotism in Peru.

In reference to American linguistics it is necessary to defer to the specialists on practically all points. These investigators would appear to have held for some time the view that the Indian as a group has not only been so long removed from the Old World that his speech affinities in that quarter are no longer recognizable, but also that he has been at home in the New World long enough to have evolved about 160 linguistic stocks or language families, with 1,200 or more dialectic subdivisions. Presumably, however, some of this language diversity may be due to migrations from different linguistic areas of the Old World.

Under the heading, finally, of somatics, it may be mentioned that the native population of the New World has been variously estimated at figures ranging all the way from 5 millions (Thomas Wilson) to 50 millions (Kroeber). Some groups being practically out of reach, as, e. g., in the Amazon region, and, therefore, not adequately studied, the precise number of distinguishable physical types can scarcely be given, but the general conditions pertaining to physical characteristics are similar to those obtaining with respect to linguistics: the Indian type is distinguishable in one way or another from its nearest Mongoloid relations and at the same time is separable, according to some authorities, into about 10 more or less distinct varieties, which, as in the case of languages, may or may not have developed since immigration took place.

All of these more or less indisputable facts, regarded as phases of the normal cultural and biological processes, are uniformly held to have required a long period of time for their accomplishment. With this assumption no issue need be taken; but the question may properly be asked—how much time? This is not the occasion for arguing the point, still it is tempting to remark in passing that if the glory which was Egypt's arose and fell in about 3,500 years—and we have very similar histories for Mesopotamia, China, and perhaps India—then there is at least some ground for the supposition that the advanced cultural developments exhibited by Peru and Middle America may not much antedate 2000 B. C. And as for the entire known

segment of the culture curve phenomenon represented in America, *viz.* the Neolithic phase and what follows, its counterpart in the Old World has never been estimated to range beyond 20,000 years,[12] while of late the figure has by some been reduced to about 7,500 years.[13] Unless, therefore, we choose to assume that the American Neolithic, with all it implies, arose full fledged out of nothing, it must have been derived from Old World beginnings and consequently be of somewhat later date, because time and space are both important factors in the normal spread of organic phenomena.

Before leaving this topic of circumstantial evidences it should be remarked that the general question of the antiquity of man in America was long ago tentatively settled by European students. To them the demonstrated geologic age of man and of his immediate precursors in the Old World has seemed sufficient warrant for claiming approximately equal human antiquity for the New World. And certainly, if a tool-using primate did actually exist in Eurasia, as is claimed by Rutot and others, so far back as early or even middle Tertiary times, it becomes rather hazardous to dispute the probability of this creature's entrance into the two Americas. Especially is this true when it is known not only that some of the contemporary animal species, like the horse, the camel, and the elephant, migrated both to and from the New World, but also that the present floral and faunal genera and even species of Eurasia and North America are in large part identical.[14] Naturally, therefore, the recent discovery of the Peking man in northeastern China has somewhat strengthened this broad claim. But, in reality, the existence of middle Tertiary man in the Eastern Hemisphere is problematic, and the unique geographic isolation of the American Continent, together with the glacial conditions which served presumably as a climatic barrier during much of Pleistocene times, cannot be ignored. Nevertheless, Sir Arthur Keith has lately reaffirmed his belief in the existence of evidence in America of truly ancient man;[15] and one might go on indefinitely citing similar opinions, but it must suffice to add merely that such experienced authorities as L. Capitan and M. Boule have both frankly accepted some of our questionable North American artifact discoveries as not only Paleolithic in form but as actually Pleistocene in date. In the circumstances we can do no less than turn to a brief consideration of these alleged discoveries.

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[12] Breasted, J. H. Scientific Monthly, 1919, p. 308. Similar estimates made by O. Montelius, R. Pumpelly, and others.

[13] Peake, H., and Fleure, H. J., in The Corridors of Time, vol. 3, pp. 140–143, Oxford, 1927; Childe, V. G., The Most Ancient East, p. 13, New York, 1929.

[14] Farrand, L., Basis of American history, chapter 4, New York, 1904.

[15] Keith, Sir Arthur, New discoveries relating to the antiquity of man, p. 29, New York, 1931.

PALEONTOLOGICAL CLAIMS

The interesting archeological contributions made from time to time by investigators in the related fields of paleontology and geology—contributions which have done more than anything else to forward the solution of the problem of the antiquity of man in America—are fortunately to be treated by a specialist. It is, therefore, not my intention here to consider this long series of tantalizing discoveries in detail, but rather to present the accumulated evidence in summary form so as to obtain something tangible on which to offer comment and likewise something with which to contrast our archeological findings.

In the course of desultory reading extending over more than 20 years, I have collected bibliographic references to alleged isolated archeological discoveries made in geologic deposits on a variety of occasions more or less accidentally. I have done this in the hope of sometime checking out the essential facts from the original publications, and thus, perhaps, arriving at a definite conclusion on the subject of antiquity. At present the checked list of such recorded items totals 187, a figure which does not include several obviously absurd claims, such as a petrified sandal found in one of the secondary formations of Nevada, or a flaked implement recently hoisted, it was said, from a Kansas oil well over 2,000 feet deep. Doubtless there are many more citations and they are increasing annually, especially since Science Service a few years ago assumed the burden of prompt and adequate preliminary investigation of all reported indications within the United States. Indeed, so numerous are these discoveries, ranging as they do from early in the eighteenth century to the present year, that only a bookworm or a confirmed cripple could have the incentive deliberately to run them down. Besides, my own ardor has been considerably dampened by the gradual realization that the final solution of the antiquity problem does not lie in this quarter but in the original open field. The recorded data, as might be expected, turned out to be of very unequal scientific worth, and even those finds most positively vouched for—which sometimes prove entirely too much—cannot now be properly evaluated. Their significance in the end will depend upon new discoveries. Nevertheless, such as they are, these reported archeological discoveries are of considerable interest, if for no other reason than the fact that they were recorded and sometimes even brought to light by men of training and wide experience in their respective professions. In addition, they have been reviewed over and over again, favorably as well as unfavorably, by equally competent authorities. We are, in

short, obliged to accept the facts as given, regardless of final interpretations.

The geographic range of these problematic discoveries extends over the greater portion of the two Americas, continental and insular. A tabular statement must suffice as a bird's-eye view of the distribution, which is as follows:[16]

Canada finds	3
United States of America finds (37 States) (49 accompanied by fossil fauna)	136
Mexico finds (2 accompanied by fossil fauna)	5
Central America finds	1
Puerto Rico finds (2 accompanied by fossil fauna)	2
Cuba finds (5 accompanied by fossil fauna)	6
South America finds (18 accompanied by fossil fauna)	34

The geologic range of the data in question is equally great and, literally accepted, far more impressive. Without pretending to supply all available details, and without mentioning the more extreme if not absurd claims, the following summary may be said roughly to indicate the horizons of the apparently legitimate findings to date:

Surface	17
Recent: Bogs, springs, sand dunes, loess	11
Pleistocene: Glacial drift, loess, Pampean formation	84
Pliocene: Auriferous gravels, pre-Pampean formations	32
Miocene: Auriferous gravels, pre-Pampean formations	7
Oligocene	1
Eocene	2
Indeterminate	23

There remains to indicate the general character of the human relics thus distributed in time and space. As elsewhere in the world, the American discoveries comprise both skeletal parts and cultural objects made of such relatively imperishable materials as stone, shell, bone, burnt clay, and charcoal—anything at all indicative of human artifice and, therefore, commonly grouped under the comprehensive term "artifacts." In presenting the list it may be instructive not only to separate the individual occurrences according to the general nature of the situation in which they were found, whether on the surface of the ground, in cave deposits, or in ordinary open-air geologic formation, but likewise to indicate the presence or absence of associated extinct animal remains, which are normally regarded as

[16] It is impractical here to cite the original sources, but nearly every treatise on American archeology supplies some, either first or second hand. See, for example: Beuchat, H., Manuel d'archæologie americaine, Paris, 1912; Hay, O. P., Amer. Anthrop., vol. 15, pp. 1–36, 1918; Hrdlička, A., Bulls. 33, 52, 66, Bur. Amer. Ethnol., 1907, 1912, 1918; Wright, G. F., Man and the glacial period, 1912.

affording a clue to the geologic age of the human relics. The discoveries and their contents thus classified are as follows:

Surface discoveries:	
Artifact finds (excluding finds in 35 States accepted by Thomas Wilson)	17
Skeletal finds (1 accompanied by fossil fauna)	1
Cave discoveries:	
Artifact finds (10 accompanied by fossil fauna)	11
Skeletal finds (13 accompanied by fossil fauna)	15
Geologic discoveries:	
Artifact finds (34 accompanied by fossil fauna)	89
Skeletal finds (18 accompanied by fossil fauna)	54
Approximate total:	
Artifact finds (45 accompanied by fossil fauna)	117
Skeletal finds (31 accompanied by fossil fauna)	70
Total (76 accompanied by fossil fauna)	187

Finally, in order to round out our summary account, it seems fitting to add a list of the extinct or fossil organisms found associated with the anthropological remains. Such a list might very well include a number of plants; but circumstances compel their omission and leave even the animal group incomplete both as to items and as to descriptions. The partial list includes:

Antelope (*Antilope maquinensis*)
Bear
Bison (*Bison occidentalis* and one or two others)
Camel
Deer
Dog
Elk
Fox
Horse (*Onohippidium, etc.*)
Jaguar (*Felis protopanther*)
Llama
Mammoth
Mastodon
Mink (*Mustela macrodon*)
Musk-ox
Peccary
Rhinoceros
Tapir
Wolf

Baromys sp. (rodent)
Chlamydotherium (armadillo)
Didelphis (opossum)
Eucastor (rodent)
Glyptodon
Grypotherium (ground sloth)
Hoplophorus
Hydrochaerus sulcidens (rodent)
Machairodus (saber-toothed tiger)
Megalocnus (ground sloth)
Megalonyx (ground sloth)
Megatherium (ground sloth)
Mylodon (ground sloth)
Neomylodon or *Glossotherium* (ground sloth)
Platyonyx (ground sloth)
Scelidotherium (ground sloth)
Smilodon (saber-toothed tiger)
Toxodon (herbivore)

This, then, is the formidable array of facts as alleged in the main by students of the fossil evidences of ancient life derived from the earth's crust and by them put forward as a demonstration of the

geologic antiquity of man in America. It is a body of data with which—apart from its human implications—the geologist and the paleontologist alone are competent to deal; but so astounding are its claims with respect to man that the archeologist is of necessity made suspicious. And his suspicion finds much to feed upon, for by confession of the paleontologists themselves the precise determination of the age of any given geologic formation is sometimes a difficult matter, not always to be settled solely by the character and composition of the fossils it contains. Indeed, the paleontologists appear to recognize that biologic forms do not correlate uniformly with absolute time any more than do cultural typology and chronology for the archeologist; in short, that form and age, or life-periods and geologic systems, are two distinct concepts which must not be confused.

To begin with, the paleontological discoveries relating to man in the New World prove entirely too much. Taken literally, they prove that the human or proto-human stock in America was sufficiently advanced to use tools already in early Tertiary times, i. e., about the time when the mammalian forms of the life are supposed to have made their first appearance; they prove that by the middle Tertiary this being had reached a stage of physical development in America equal to that shown by man in Europe for the first time toward the latter end of the Pleistocene; and they prove likewise that by the middle Tertiary human culture in the New World, as represented by chipped and ground stone implements, was on a level with that achieved for the first time in the Old World only about 7,000 to 10,000 years ago. Stated in another way, the alleged evidence goes to show that neither man nor his culture in America has changed appreciably since middle Tertiary times, while in Europe, Asia, and Africa such changes, though locally varied, have been more or less profound. The upshot of the whole matter is, therefore, naturally enough that the evidence cannot be—and rarely has been—taken at face value. Almost all of the finds have been disputed and in many cases satisfactorily explained away. But not all the finds have been thus disposed of, nor, indeed, can be, because the facts in several instances—as for example the peculiar lance points associated with skeletons of an extinct bison at Folsom, N. Mex.—are acceptable to all observers. Moreover, it is a curious fact that though discoveries pointing to the geologic antiquity of man in America have been reported and either ignored or discredited for more than 200 years, they still keep coming in ever increasing numbers and in more and more carefully authen-

ticated form.[17] The final decision about the antiquity of man in America cannot, therefore, be very far off; but in the meantime the archeologist has taken his last stand in urging that these isolated archeo-paleontologic discoveries may not be as old as the associated faunal remains and the attending geologic conditions would seem to indicate. This stand the archeologist is forced to take on grounds which will be set forth in the following section.

ARCHEOLOGICAL DATA

In turning now to the sphere of archeology proper, namely, the investigation of strictly artificial deposits which testify to the presence and activity of early man, we at once enter the field where the writer is most at home and arrive at the point of view from which the whole subject of the antiquity of man in America is regarded in the present essay. The body of American archeological data already recovered is very large, and, as those things go for the world as a whole, is derived from a notable variety of well-distributed sources. Our collections naturally are not of uniform scientific value, but much of the material excavated during the last 3 or 4 decades compares favorably with the best results achieved by foreign workers in their own fields. As a body of evidence illustrative of prehistoric life and culture, this material, when properly arranged with respect to time and analyzed with respect to the forms and functions of its various traits, is at once consistent with itself and also in reasonable agreement, as far as it goes, with the corresponding data from the rest of the world, but at the same time considerably at variance with the summarized claims of paleontology. To make clear the nature of this disagreement it will be necessary to outline briefly both the positive and negative archeological features which bear directly on the antiquity problem.

POSITIVE EVIDENCE

The simplest method of determining the general sequence of development of past biological phenomena is to observe the natural order in which the fossil remnants of the process are laid down in the

[17] Note appended 1935. Since this was written reports have been published demonstrating beyond question the association of cultural and extinct animal remains at Gypsum Cave, Nev.; Burnet Cave and Clovis (gravel pit), N. Mex.; and Scottsbluff (loess deposit), Nebr. See respectively, Southwest Mus. Papers, no. 8; Mus. Journ. Univ. Pennsylvania, vol. 24, pp. 61–158; and Amer. Anthrop., vol. 37, pp. 306–319. Scarcely less important but only partially described skeletal and cultural finds have been made also at Pelican Rapids and Browns Valley, Minn., and at Dent and Fort Collins, Colo. See, e. g., Proc. Nat. Acad. Sci., vol 19, pp. 1–6; Science, vol. 80, p. 205; Proc. Colorado Mus. Nat. Hist., vol. 12, pp. 4–8, and vol. 14, pp. 1–4; and Science News Letter, Nov. 2, 1935, p. 277.

stratified deposits of the earth's crust. It is the method followed by paleontologists and paleobotanists; and, provided the enclosing crust is undisturbed and of reasonable thickness, it is obviously a fairly reliable mode of procedure. The archeologist of necessity utilizes the same stratigraphic principle in unraveling the time order of cultural phenomena, as laid down, however, only in the relatively small accumulations of artificial debris left behind mostly on the surface of the earth as byproducts of former human occupation. Such refuse deposits are available in countless numbers; are of several different types, residential and occupational; are found in both natural shelters and in open-air locations; and are distributed over nearly all the known habitable portions of the globe. In Europe, and to some extent elsewhere in the Eastern Hemisphere, these deposits have yielded a fairly complete record of man and of his doings from middle Quaternary times to the present. In America, if man was indeed living here also during these early days, it would seem that we might expect indications of the fact to occur in much the same manner as elsewhere and to the same extent. Let us review the available evidences.

Number of culture deposits.—As already remarked, the Western Hemisphere is richly strewn with monumental proofs of early human activity. Leaving out of account our many wonderful ruins and our stupendous earthworks as being of relatively recent date and of secondary importance for present purposes, we have left for consideration incidental accumulations of settlement and workshop debris in number and variety as remarkable as those of any other region of the world. These archeological features range from the Arctic through the Tropics to the sub-Antarctic, i. e., from the Eskimo territory of Alaska, Greenland, etc., to the almost equally inhospitable habitat of the now nearly extinct Onas and other primitive tribes of Tierra del Fuego. In the form of shell-heaps or kitchen-middens they line both our Atlantic and Pacific shores, while inland they occur as ordinary camp and village refuse, as a rule thinly spread out, but sometimes heaped up either in the open or concentrated within restricted limits of caves and rock shelters.

Thickness of culture deposits.—The actual thickness and volume of these culture deposits are of some significance, though naturally difficult to interpret in strict chronological terms. So far as known, American shell heaps appear not only to spread out horizontally rather more than those of the Old World, but they also exceed them in vertical dimension. Thus while heights of fully 30 feet have been personally recorded more than once, for instance, in the San Francisco Bay region, and a single pile in Florida was estimated at about 45 feet, and while doubtful reports from Brazil claim 100 feet, the extreme figure for the Old World—vaguely recollected as re-

ferring to Australian shell-heaps—is only 40 feet. The value of such comparison is, however, vitiated somewhat by two facts. For one thing, even if our American shell-heaps exceed, let us say, those of Europe in all dimensions, it must be remembered that the latter were abandoned some 2,000 to 3,000 years ago, while the former have been occupied practically to the present day. For the other, American shell-heaps reveal only Neolithic culture traits, while those of Europe carry, for example, flint-working back to the Azilian (Mugem, Portugal) and even to the Solutrean (Altamira, Spain) phases of the industry. In other words, the shell-mound phenomena of Europe and America are not quite the same either culturally or chronologically.

When we turn to the comparison of inland culture deposits, the case is still more unpromising. At Pueblo Bonito in New Mexico I once laid bare in an old, weathered, free-lying rubbish-heap a stratified section fully 16 feet in height,[18] and Dr. Kidder at the Pecos ruins in the same State has excavated a similar deposit, originally pitched over the edge of a cliff against which it rested as talus, measuring fully 20 feet in depth.[19] Some of our American caves in the Alleghany Mountains, in the Ozarks, in the Sierra Nevadas, and in the southern reaches of the Rocky Mountains have yielded debris formations of appreciable thickness, especially in the last-mentioned locality, otherwise known as the Cliff Dweller region of the Southwestern States. The extreme depth so far recorded I am unable to learn on short notice from the many active workers in the field, but it scarcely exceeds the 40 or more feet registered by the shell heaps.[20] But this New World record is definitely exceeded by that of the Old World on two separate counts: First, by the greater depths of the strictly corresponding Neolithic and later culture deposits of recent geologic date, and, second, by supplementary Paleolithic strata of Pleistocene date for which we have as yet no counterpart. By way of illustration, it may be cited that at Knossos, in Crete, the Neolithic stratum alone was 21 feet thick, and adding the later prehistoric accumulations representing the Bronze and Iron Ages, the total depth of culture debris was over 38 feet;[21] at the Anau kurgan sites in Russian Turkestan the stratified rubbish rose to a combined total of 170 feet, of which 45 were taken up by the Neolithic level;[22] and one mound at Susa, in southern Mesopotamia, according to the lowest of many published

[18] Nat. Hist., vol. 21, p. 14, 1921.

[19] Kidder, A. V., An introduction to the study of southwestern archaeology, pp. 18, 31, New Haven, 1924.

[20] Requests sent to several working archeologists for figures resulted in nothing definite.

[21] Evans, Sir A., The Palace of Minos at Knossos, p. 33, London, 1921.

[22] Pumpelly, R., Explorations in Turkestan, Carnegie Institution Publ. no. 26, p. 50 and pl. 5, Washington, 1904.

figures, attained a height of about 100 feet, 65 of which were representative of the Neolithic culture.[23] But that is not all of the Old World story, for below this tremendous thickness of Neolithic and post-Neolithic debris there lies, chronologically speaking, a no less impressive stratum of Paleolithic camp refuse, amounting at the Prince's Cave in Italy to 52½ feet and at the Castillo Cave in Spain to over 55 feet.[24] Clearly, the Old World was formerly ahead of the New as regards quantity of production, or else it had a very much earlier start.

Geologic situation of culture deposits.—The precise relations of these archeological deposits to their geologic and topographic surroundings are also of no little importance as affording possible clues to the passage of time. As stated, most of our rubbish heaps lie actually on the surface of the ground or, what amounts to the same thing, in open caves. There are instances, however, here as in the Old World, in which the culture debris has been sealed up, as it were, in the earth's crust by various natural forces—covered up, that is, by vegetal mold either on dry land or in water, by wind or water-borne deposits, by earth slides and lava flows, by stalagmitic formations, and even by the gradual accumulation of scaling or disintegrating cave-roof material. Fairly common also are vertical coast-line movements, which by subsidence bring about the submergence and, perhaps, subsequent silting over of cultural deposits and by elevation leave what were once beach settlements some distance higher up and inland. Some of these processes are accomplished only by slow stages, and in given situations consequently afford a rough estimate of time elapsed.

The New World furnishes examples of all these indicated possibilities. Hearth sites and habitation floors have been reported directly to the writer as occurring, for example, at some depth in the vertical banks of both the Missouri and Columbia Rivers, and he has himself observed minor indications of the same sort in various arroyos of the Southwest. Possibly our much-disputed Trenton argillite or yellow soil culture may belong to this type of inhumation. Stalagmitic formations covering culture debris are not unknown occurrences in our caves, and we are just now waiting to learn exactly how much sterile cave debris has accumulated over the oldest apparent culture level in the Gypsum Cave being excavated in Nevada.[25] Partially submerged shell-heaps have been reported and

[23] De Morgan, J., Prehistoric man, p. 13, London, 1924.

[24] Obermaier, H., Fossil man in Spain, pp. 84, 162, New Haven, 1924. But meanwhile Tabun Cave in Palestine has yielded a culture deposit measuring about 70 feet in thickness. See Garrod, D. A. E., Excavations at the Wady al- Mughara (Palestine) 1922–33, Bull. 10, Amer. School Prehist. Res., pp. 7–11, May 1934.

[25] Stock, Chester, Sci. Monthly, pp. 22–23, Jan., 1931; Harrington, M. R., The Gypsum Cave, etc., The Masterkey, vol. 4, no. 2, 1930; Sci. Amer., pp. 34–36, July, 1930.

are also personally known on both the Atlantic and Pacific shores of the United States; and, curious as it may seem, they agree in registering a subsidence of about 17 feet.[26] As to evidence of shore elevation, such has been reported recently from the Hudson Bay region, where occur culturally distinct Eskimo habitation sites lined up on successive raised beaches.[27]

Some of these archeo-geologic facts are impressive enough considered chronologically; but, unfortunately, the time involved is in nearly every case difficult if not impossible to gage. The most conspicuous instances of geologic action, as, for example, the coastal subsidences indicated, might have happened in a moment—at least in California; the flood plain deposits covering the hearth sites mentioned might have resulted from a single torrential rainstorm. Stalagmitic formations depend upon a variety of unstable factors; and even the growth of a superficial layer of vegetable mold might have been affected by climatic fluctuations. To the writer, the most convincing phenomenon would be the covering accumulation of sterile floor debris derived solely from the disintegrating walls and ceiling of a dry cave; but, unfortunately, no precise figures are readily available on the subject.

Broadly considered, the cited geologic relationships of the cultural deposits agree with the vertical dimensions attained by the artificial debris heaps as such in arguing for a really considerable period of time to account for what has taken place. But, after all has been said, we have nothing in America to compare with the similar archeological occurrences, for example, in the travertine deposits at Ehringsdorf, Germany, in the loess formations at Achenheim, Alsace, and in the gravel terraces of the Somme at St. Acheul and at many other places up and down western Europe where hearth sites are preserved in situ. The Gypsum Cave looks promising; but, so far as now known, the sterile rock and cave earth stratum here covering the lowermost culture-stratum is thin in comparison with the similar accumulations found in many of the European caves.

Fossil contents of culture deposits.—When we examine the zoological contents of our stratified culture deposits we find other suggestions of age. In the case of some of the great shell-heaps it has been repeatedly observed that the shells making up the lower portion of the debris are more broken up and disintegrated than those of the upper part of the heap.[28] It has also been observed, for

[26] Abbott, C. C., Primitive industry, p. 449, quoting G. H. Cook; Nelson, N. C., The Ellis Landing shellmound, Univ. California Publ. Amer. Archæol. and Ethnol., vol. 7, no. 5, pp. 364–6 and pl. 49, 1910.

[27] Mathiassen, T., Archæology of the Central Eskimos. Rep. Fifth Thule Expedition, 1921–24, vol. 4, pt. 1, pp. 6 seq., 86, 129, 226 seq., Copenhagen, 1927.

[28] Wyman, J., Amer. Nat., vol. 1, p. 571, 1868; Rau, C., Smithsonian Rep. 1864, p. 372, 1865; Nelson, N. C., op. cit., p. 374, pl. 39.

example, in Maine, that the living representatives of shell species found in abundance in the mounds are today in some cases apparently scarce and in other cases certainly smaller.[29] In other places, like Vancouver Island, no appreciable changes are said to have taken place during man's presence; [30] but at the northern end of San Francisco Bay the oyster presumably flourished during shell-mound occupation days, though it is now absent; [31] and on the Pacific coast of Panama and adjacent parts of South America the culture deposits contain four shell species which have become locally extinct, one of them surviving at present only on the Atlantic side.[32] Equally important suggestions are yielded by the mounds in the shape of vertebrate remains. Bones, e. g. of the extinct Great Auk [33] and of a certain giant mink [34] are said to occur in the shell-heaps along the Maine coast; likewise bones of the locally extinct wild turkey and other game animals recently hunted down here, as in most of the eastern United States, by the white man. The inland culture deposits in both caves and mounds rarely contain shell remains, but, as might be supposed, they are fully as rich as the littoral refuse heaps in bird and mammal bones. Nevertheless, in spite of all the apparently favorable circumstances, and in spite also of the reasonable expectations created by the cited paleontological discoveries, no extinct or fossilized animal remains of any real importance have been found in these artificial deposits. The partial exception is the peccary, which would appear to have been locally exterminated by native hunters of prehistoric times; but while the species is extinct in the United States, its bones as preserved in our Indian caves are not old enough to have undergone fossilization.[35] We are obliged, therefore, to dismiss this biological approach to our problem with the observation that, like the aspects previously considered, it yields indications of moderate antiquity, but, as a whole, the evidence so far produced tallies with the observations made on such of the corresponding cultural deposits in the Old World as are by common consent accepted as of Holocene or Recent geologic date.

Implemental contents of refuse heaps.—As most important of all, we have finally to consider the nature and condition of the strictly cultural contents of our archeological deposits. If circumstances permitted, we should pass in review, as it were, in stratified chrono-

[29] Abbott, C. C., Primitive industry, p. 445.

[30] Smith, H. I., Nat. Mus. Canada, Ann. Rep. 1927, p. 45.

[31] Nelson, N. C., Shellmounds of the San Francisco Bay region. Univ. California Publ. Amer. Archæol. and Ethnol., vol. 17, no. 4, p. 337.

[32] Linné, S., Darien in the past, pp. 127–34, Göteborg, 1929.

[33] Loomis, F. B., and Young, D. B., Amer. Journ. Sci., vol. 34, pp. 24, 29, 1912; Wyman, J., op. cit., p. 578.

[34] Loomis, F. B., Amer. Journ. Sci., vol. 31, pp. 227–29, 1911.

[35] Mercer, H. C., and Pilsbry, H. A., An exploration of Durham Cave, Pa., Publ. Univ. Pennsylvania, vol. 6, pp. 165, 173–8, 1897.

logical order, all the special contrivances made and used by the American aborigines—their tools, utensils, weapons, ornaments, ceremonial objects, and whatever else of designed handiwork has been preserved in shape suitable for comparison with a like array of cultural traits from the Old World. Paired off in this way, trait by trait, the two markedly similar outputs of art and industry would visibly demonstrate three important desiderata, viz: (1) The approximate stage or level in the evolution of technological processes back to which our American activities extend; (2) what actual inventions had been made in the Old World prior to that level being reached; and (3) by inference from Old World conditions the approximate geologic date at which the invasion of the American Continent must have taken place. As it is, the desirable comparisons can be submitted only in the most general terms.

In approaching this subject it is in order to remark that from the time of the first discovery of our widely disseminated living tribes their obvious localized cultural peculiarities and varying stages of general development have been noted and commented upon until, not long ago, Wissler and others, as before stated, tentatively divided their entire habitat into as many as 15 distinguishable culture areas, some of which were and are in large part special adaptations to differing geographic environment. Insofar as any chronological interpretations were placed upon this distributional phenomenon, it was tacitly assumed that the highly developed centers of culture were of relatively late origin, while the primitive centers were correspondingly older and represented the ancient conditions out of which the advanced cultures had sprung. When later on, about a century ago, archeological investigations began in earnest, it was soon discovered that in some ethnological culture areas the surviving trait peculiarities extended on into the prehistoric past with only minor modifications, while in other localities there were indications of complete or partial changes, in the form of new and altered features. In the latter situations it was natural to proceed as before in devising chronologic arrangements—genetic connections for the whole localized culture complex were assumed and schemes of relationship worked out by placing the crude and generalized trait groups at the bottom and the refined or specialized groups at the top. By such simple methods of seriation tentative chronologies have been built up, for instance, for Peru and parts of Middle America. Nothing like a reliable history of culture could be established in this way, however, and it has remained for archeologists of the last three or four decades to demonstrate here and there the actual time order of cultural events by strictly observing and recording the sequence of artifact phenomena as laid down in the stratified

refuse deposits. This work, if not absolutely finished anywhere, has at least been carried a long way forward, especially in the Southwestern United States, including California; it is well under way in the Eastern States; and has recently been begun also in Mexico, where it offers and has already yielded promising results.[36]

And what, it will be asked, are these results in which so much confidence appears to be placed? Briefly, the answer is twofold: We have, for one thing, made certain that some of our refuse deposits do nearly everywhere record definite modifications and, as a rule, advancements of the culture process; and, for the other, we have made almost equally certain that the earliest developmental stages represented by the bottommost levels of debris are not truly primitive.

More specifically, concerning the first point, it has been reported by many observers over a long period that within the ceramic areas of both North and South America there exist refuse deposits, some of which contain pottery while others do not.[37] Such a condition warrants the inference that the two occurrences are not of the same age, though it scarcely indicates which is the older. This question is settled, however, by the fact that refuse deposits have been excavated in scattered sections of the United States, from the Atlantic to the Pacific, the lower levels of which register the positive absence of ceramics and the probable absence also of maize culture with its associated features, while the upper levels yield all of these elements, occasionally, as in the pueblo area, strung out in a long succession of graded steps marking presumably the whole period of human occupation.[38] Whether or not anything similar has yet been found in South America is uncertain; but, in any case, the condition undoubtedly exists stratigraphically, as it is known to do geographically. The essential significance of this preceramic culture stratum seems to be that most of the United States at one time, like most of Canada today, was inhabited solely by a roaming population which lived entirely off the natural products of the land, and that the maize complex with its pottery, as well as certain flaked, chipped, and ground-stone implements, by slow stages crept over the country from the south and had already reached the St. Lawrence or its approxi-

[36] Vaillant, G. C., Excavations at Zacatenco. Anthrop. Papers Amer. Mus. Nat. Hist., vol. 32, pt. 1.

[37] Personal observations by F. G. Speck and N. C. Nelson at Tadoussac, Quebec Province; Rau, Charles, Smithsonian Contr. Knowl., vol. 25, p. 225, 1884; Hawkes, E. W. and Linton, R., Pre-Lenape culture in New Jersey, Amer. Anthrop., vol. 19, p. 487, 1917; Linné, S., *op. cit.*, pp. 52, 59, 271.

[38] Harrington, M. R., The rockshelter of Armonk, N. Y., Anthrop. Papers Amer. Mus. Nat. Hist., vol. 3, pp. 125–36, 1909; Nelson, N. C., Contributions to the archæology of Mammoth Cave, Ky. (1917) and Chronology in Florida (1918), Anthrop. Papers Amer. Mus. Nat. Hist., vol. 22, pls. I and II; Harrington, M. R., The Ozark Bluff Dwellers, Amer. Anthrop., vol. 26, no. 1, p. 12, 1924; Roberts, F. H. H., Jr., Bull. 92, Bur. Amer. Ethnol., pp. 1–9, 1929.

mate natural limits in the northeast when America was invaded by the white man.

As to the second point, viz, the general status and detailed characteristics of our early hunting culture, the answer must be less precise and categorical. The essential facts are not yet available for the eastern half of North America, though tolerably well in hand for the Ozark region and especially abundant for the Southwest and adjacent parts of Mexico, where the associated traits are termed the "Basket Maker culture." Basket Maker relics have been known for nearly half a century, but their importance as antedating the prehistoric Pueblo developments was scarcely appreciated until about 20 years ago, when Kidder and Guernsey took up their investigation in earnest.[39] The remarkable thing about this culture stratum, as now known, is that although it may be 3,000 or 4,000 years old, and is at least in part devoid of pottery and almost if not quite devoid of maize, positively lacking in bows and arrows, in chipped stone arrow points, grooved axes, etc., it is at the same time rich in basketry, in textile work—especially ornate sandals; in wood work—including spears and spear throwers; in ordinary bone work; in polished and drilled stone work, as exemplified by beads, pipes, etc.; and, lastly, in ordinary flaked and chipped stone work taking the form of lance points and knives. To these accomplishments may be added the possession of the domesticated dog and possibly the turkey. All in all, such are the taste and skill displayed by these primarily hunting folk that, however distant they may have lived in time, their achievements rest on long prior developments not yet discovered. Moreover, from the manner in which maize culture and ceramics gradually developed among them and their successors, the Pueblos, it seems probable that the Basket Makers were from the start subject to influences from more advanced cultures in the south. Perhaps, therefore, Middle America is the place we should go to for the complete story of cultural evolution in America.

When we turn to the earliest archeological remains found in stratified culture deposits in other parts of the United States, the records, as stated, are much less complete; but, as far as they go, the inventories obtained are in general agreement with that of the Basket-Makers. Thus, the surviving implemental traits, for example, of the California and Florida shell-heaps, as well as of the cave deposits in Kentucky, Pennsylvania, New Jersey, and New York, are confined largely to works in stone, bone, and shell; the finished products everywhere show more or less of quantitative changes, as well as gradations of workmanship and specialization of form; and,

[39] Guernsey, S. J., Explorations in northeastern Arizona. Peabody Mus. Papers Amer. Archæol. and Ethnol., vol. 12, pt. 1, p. 118, 1931.

most important of all, the oldest items recovered in the line of flint-chipping are far from primitive, or at least from anything comparable to the pre-Solutrean of Europe. The same is true even if we go to Alaska, the main front entrance to the American Continent and which by many is regarded as harboring a culture derived from that of the Upper Paleolithic of Europe. The similarity seems real enough, at least so far as bone work is concerned; yet the associated chipped stone work, say, from Point Barrow and other well-known archeological stations, is of much more modern stamp. Indeed, the very chipped-stone items recovered from the supposedly late post-glacial formations at Trenton, N. J.,[40] at Melbourne, Fla.,[41] and at Folsom, N. Mex.,[42] are of full-fledged Neolithic design and workmanship, the like of which were not achieved in the Old World, according to the latest archeological time-reckonings, until some 7,000 or 8,000 years ago.

It may be objected that the New World Neolithic need not have waited on that of the Old World; that it might have developed independently. To this the most natural answer is that it obviously had to wait, because there are in America no known rude preliminary stages of flint working corresponding to those characterizing the Upper Paleolithic of west Europe and north Africa, and from which our rich and highly developed American Neolithic flint industries could have been derived. But this ready old answer may no longer suffice, because, for one thing, it is becoming increasingly evident that the mentioned Upper Paleolithic of Mediterranean Africa and Atlantic Europe is not even directly ancestral to the succeeding local Neolithic and need not therefore be considered as the necessary forerunner of our American Neolithic. In the light of the more recent archeological discoveries covering the Old World as a whole, the so-called "Caspian flake industry", with its several successive stages, characteristic especially of North Africa and the very similar contemporary Aurignacian, Magdalenian, and Azilian-Tardenoisian developments at home in west Europe, appear as unique specializations such as have not arisen at all uniformly in other parts of the Old World any more than in America. In place of these flake industries we find another tradition, a core industry, familiar to us through a succession of stages called pre-Chellean, Chellean, Acheulian, Mousterian perhaps, Solutrean, Campignian, and Neolithic. This still obscurely related succession really seems to constitute the

[40] Volk, E., The archæology of the Delaware valley. Papers Peabody Mus., vol. 5, 1911; Spier, L., The Trenton Argillite culture. Anthrop. Papers Amer. Mus. Nat. Hist., vol. 22, pt. II, 1918.

[41] Gidley, J. W., 45th Ann. Rept. Bur. Amer. Ethnol., pp. 7–8, 1927–8.

[42] Figgins, J. D., Antiquity of man in America. Nat. Hist., vol. 27, pp. 229–39, 1927; also various papers read by Barnum Brown but apparently not yet published.

main current of the world's flint-working developments, and may possibly be the real source of our American flaked- and chipped-stone industries. Indeed, were we to look closely at our so-called "Neolithic" inventories, we should easily recognize—besides the mentioned Eskimo bone objects of Upper Paleolithic type—such items as our widely distributed wooden spear and spear thrower, perhaps of Magdalenian affinity; our three out of four forms of Solutrean chipped blades; our ordinary Aurignacianlike end scraper; our simple Mousterian type flake;[43] and, finally, our Acheulian and Chellean varieties of the coup-de-poing. It is not an impressive list, nor is it offered as evidence occurring either in isolation or in stratified order; it is presented merely as something reminiscent chiefly of the Old World's core industries. Wherever its actual origin or whatever its routes of distribution, this industry was truly ancestral to the real Neolithic of the Old World and may also very well underlie our American Neolithic. But whether this substratum of the Neolithic actually arrived in America during its Solutrean phase is extremely doubtful, because the close relation of the Old and New World Neolithic would seem to be attested by the fact that the two cultures have at least 85 objective elements in common (54 being stone implements), besides strong similarities among several other less material traits. Stated otherwise, the indications are that the Neolithic complex was already taking shape in Eurasia before its carriers invaded the American Continent, though the date is not necessarily limited by the supposed earliest Neolithic developments in Egypt placed at about 5500 B. C.

Patination on stone implements.—It is a toss-up now whether the question of patination, by which is here meant the weathered condition of stone artifact surfaces due either to mechanical wear or to chemical alterations, should be treated under a positive or under a negative heading. Either position involves the admission of numerous exceptions; but inasmuch as several positive claims and actual demonstrations have been made from time to time we may as well dispose of the subject here. At the outset it must be premised that while patination, which is simply nature's way of effacing the work of man and reclaiming it as her own, is undoubtedly a valuable criterion of age, it is at the same time a most difficult phenomenon with which to deal effectively. Thus, to secure valid results by the ordinary comparative method is next to impossible, because the essential factors involved in the patinating process are rarely if ever constant; that is to say, identity of raw materials to be affected and the identity likewise of the predisposing physical and chemical activities do not obtain over any considerable portion of the world.

[43] Sarasin, Paul, Zur Frage von der prähistorischen Besiedelung von Amerika. Denkschr. Schweizerischen Nat. Ges., Mém. Soc. Helvétique Sci. Nat,. vol. 64, mem. 3, 1928.

Each case of patination, therefore, has to be treated independently, and whatever comparisons are instituted the resulting conclusions can have only the merest general significance.

With these precautions in mind, it is legitimate to cite sporadic instances of American patination. To begin with, our petroglyphs, or abraded rock-pictures, of the Southwest and elsewhere, admirably illustrate the phenomenon in all its stages, from fresh-looking artificial surfaces to such as have weathered into an exact resemblance of the adjacent natural crust. In our collections from Texas and other parts of the country, and even in the literature, occasional stone implements appear which exhibit a worn, shiny, polished surface, much like that produced on natural pebbles by the action of blown desert sands.[44] As examples of chemical action may be mentioned the chipped argellite implements from the yellow soil at Trenton, which exhibit a graduated alteration in the rock substance from the surface inward, reaching depths measuring appreciable fractions of an inch. Lastly, it is necessary to mention the claims made by the late Prof. N. H. Winchell concerning the degrees of patination exhibited by a large collection of flaked chert material gathered for him by J. V. Brower in northeastern Kansas. Winchell, after much study of his material, distinguished no less than six stages of patination, or, better expressed, six successive attempts at flaking the specimen into shape. Four of these stages he regarded as of Neolithic date and workmanship, while the other two were declared to be Paleolithic.[45]

Critical comment on both the facts and their interpretations, as outlined, is obviously premature, although called for in some form. Winchell's bold effort to prove the antiquity of man in America reminds one strongly of the earlier attempts by Thomas Wilson; yet, although Winchell's method was essentially sound, his conclusions are scarcely more acceptable until his material has been checked over by someone thoroughly familiar with artificially worked rock surfaces. From what little I have personally been able to see of the Kansas collection stored at the Minnesota Historical Society Museum in St. Paul, I am far from convinced of anything like six discernible artificial surface conditions; but even if they exist, it does not follow that any of them are necessarily of Pleistocene date. We need here, as in the Trenton case, to have the opinion of both the mineralogist and the chemist as to what has really happened, and whether or not time is a uniformly important factor in the process. Furthermore, our most patinated artifacts are not of true flint like those of Europe, so that comparison is out of the question. When

[44] Moorhead, W. K., The Stone Age in North America, vol. 2, pp. 352–3, 1910; Winchell, N. H., The weathering of aboriginal stone artifacts. Coll. Minnesota Hist. Soc., vol. 24, pt. 1, pp. 151–168, pl. 15, 1916.

[45] Winchell, N. H., op. cit., pp. 37, 170.

we examine our jasper, chert, agate, hornstone, and other flintlike specimens, we rarely find more than the faintest trace of weathering—nothing, at any rate, to compare with the shiny ochreous condition of many of the flint coup-de-poing specimens from the Lower Paleolithic, e. g., of western Europe. At the same time, it is necessary to bear in mind that the patina on European flint artifacts does not always vary according to age. Thus, while the worked flints removed from the dry rock-shelter type station at Le Moustier show no appreciable traces of patination, the specimens from the open, wet La Micoque and later stations are sometimes chemically altered to a creamy white cheeselike substance, the like of which I have not observed in America. Clearly, however necessary time may be as a factor in patination, certain other conditions are far more important. And even if the chert specimens from Kansas do yield six discernible stages of surface alteration, it may be replied that available Paleolithic specimens, also of chertlike material, from the Libyan desert adjoining the Egyptian section of the Nile Valley, exhibit perfectly astounding alterations, reaching by gradations to nearly an inch in depth. In short, while our American patination studies leave much to be desired, the warranted inference is in close agreement with the preceding conclusions derived from the stratified refuse deposits; a respectable antiquity is indicated, but a lapse of time comparable to that demonstrable for the Old World is out of the question.

NEGATIVE EVIDENCE

An attempt has been made in the preceding section to set forth the essential archeological features supplied by the New World and to make the most of their possible antiquity. The results are dubious. On the one hand, our culture deposits, with respect to geological situations and zoological contents, furnish indications of perhaps somewhat greater age than the strictly corresponding phenomena of the Old World; but, on the other, their implemental contents appear to be of Neolithic complexion—unless we boldly redefine the term Neolithic and under cover of a broader conception carry our oldest prepottery stratum back toward the illusive Old World Solutrean stage. Whether or not this can be done is doubtful on account of a number of negative indications, which can only be mentioned in bare outline.

Missing utilitarian features.—Of first importance, is the fact that our American flint-chipping industries have failed to produce in clearly specialized form a number of typical Paleolithic tools and weapons, such as the plain and notched side-scrapers (racloirs), the keel scraper, the Audi and Chatelperron points, the gravette blade, the burin with its many modifications, the point with one basal

notch or barb, the saw or serrated blade, and, most striking of all, the various geometric microliths. It is true that some of these special adaptations can occasionally be matched in a rough or generic style, but not with real precision or for any considerable geographic range.

Missing representative art features.—One of the outstanding modes of expression resorted to by European and African Paleolithic man was his faithful pictorial representation of the contemporary animals on which his existence largely depended. The long list of faunal species thus depicted, either by incising or painting on limestone cave walls or by engraving and sculpturing on pieces of bone, antler, and ivory, or again, on rare occasions, by modeling in clay, are now mostly extinct or else have migrated to suitable northern and southern climates. This fact of itself—apart, i. e., from confirming paleontological remains in the contemporary culture debris—strongly corroborates the passage of time indicated by attending geologic circumstances. Now when we turn to look for similar art phenomena in America we are unexpectedly disappointed. We have animal pictographs of all kinds in abundance, and also we possess a respectable amount of zoomorphic engraving on bone and shell, sculpturing in stone, painting on pottery, modeling in burnt clay, casting or hammering in metal, and even animal representations thrown up in the form of earthworks; but positive representation of extinct species is wanting.[46] It is true that some suggestive indications are available. There are, for example, the supposed elephant mounds of Ohio and Wisconsin, the elephant pipes done in stone from Iowa,[47] the Lenape stone tablet with an incised elephant from Pennsylvania,[48] a deer humerus with an incised stylicized proboscidian from Missouri,[49] a piece of seashell with some indefinite lines upon it, variously interpreted as a mastodon or a bison, from Delaware,[50] and certain alleged architectural sculptures resembling elephants in Middle America.[51] For good measure, a journalistic expedition to the Grand Canyon recently published photographs of one petroglyph called a dinosaur and another suggesting a rhinoceros.[52] Perhaps there are others. However, some of these representations are probably nothing more than accidental resemblances, while others have

[46] But see possible representations of Megatherium and Glyptodon, fig. 215, 5 and 7, in Archaeological Research—Chaco-Cordillera Exped., 1901–2, by Eric von Rosen, Stockholm, 1924.

[47] Proc. Davenport Acad. Nat. Sci., vol. 2, p. 249; vol. 3, p. 132; vol. 4, pp. 1–95, 1885.

[48] Bull. 30, Bur. Amer. Ethnol., p. 764.

[49] Nat. Hist., vol. 21, pp. 591–97, 1921.

[50] Lucas, F., Animals of the past, p. 171, New York, 1922.

[51] Smith, G. Elliot, Elephants and ethnologists, p. 20, pl. 2, London, 1924.

[52] The Doheny Scientific Expedition to the Hava Supai Canyon, Northern Arizona, Publ. Oakland Mus., p. 27, Oakland, Calif., 1924.

been adjudged plain frauds. Whatever the truth, the available pictorial evidence is insufficient as proof either of man's antiquity or of the late survival of the animals in question, especially as no finds seem to be extant of the actual human use of fresh ivory.

But then, as if to reinstate all the foregoing weak claims, or at any rate to confuse once more the entire issue, it must be mentioned that several widely scattered paleontological discoveries agree in suggesting the contemporaneous existence of man and of the great proboscidians, and that the latest exceptionally well-authenticated find, in Ecuador, would seem to bring the survival of the mastodon, at least, down to within two millenniums of our own day.[53] Something apparently is wrong somewhere when we are asked to believe that the American Indian, who more or less faithfully pictured the animal life about him much as did his hunting kin in the Old World, was little if at all impressed by his most unique and gigantic contemporaries. Moreover, if he saw or pursued such prey, it is strange that our folklorists have not found tales of the adventure.

Missing somatic features.—There is current among paleontologists an old and seemingly well-founded opinion to the effect that America was never the home of any anthropoid creatures from which a human stock could have been derived. Moreover, barring Ameghino's hopeless claims, there appears not to have been brought to light in the Western Hemisphere a single fragment of evidence indicative of a really primitive human type, comparable, for example, to *Pithecanthropus erectus* of Java, the Peking man of China, the Piltdown man of England, the Heidelberg man of Germany, or even of the Neanderthal type of man, widely distributed in Europe and Africa, reaching Asia and perhaps also far away Australia. In view of the apparent wanderings of this primitive hunter, it seems more than strange that he should not also have followed the game animals on which he subsisted off into the Western Hemisphere, if the route was really open. Nevertheless, American skeletal remains, and especially those for which geologic antiquity has been claimed, have all been carefully studied, or restudied, by Hrdlička,[54] who finds in the lot of 70 or more specimens only modern types of men, closely resembling our living Indians. It is true that so experienced an anatomist as Sir Arthur Keith has sought to establish the contemporaneity of the species *Homo sapiens* and *Homo neandertalensis*, or, in other words, to claim much greater antiquity than hitherto for modern man:[55] but even if proved correct for the Old World, the outcome for the New World would remain doubtful. The most extreme suggestions

[53] Uhle, Max., Proc. 23d Int. Congr. Americanists, pp. 247–258, New York, 1930.
[54] Hrdlička, A., Bulls. 33, 52, 66, Bur. Amer. Ethnol.
[55] Keith, Sir A., Antiquity of man, London, 1915.

ever made are that the Lagoa Santa skulls of Brazil have by some been referred to as being similar to those of European men of Aurignacian times,[56] while to others these same and similar skulls from both North and South America have been likened to the skulls of native Australians,[57] i. e., to a non-Mongoloid and, therefore, supposedly a pre-Mongoloid inhabitant of the New World. But as a whole our American somatic collections of whatever locality appear to be accepted as exhibiting no very marked changes with the passage of time or any wide divergence from those of their nearest neighbors, the Mongoloid branch of the existing human family.

Failure of systematic investigations.—A most striking feature of American aboriginal antiquity researches is the fact that our questionable data are the results mostly of isolated accidental discoveries. Deliberate investigations by both paleontologists and archeologists, extending through nearly a century of time and ranging over most of the continent, have yielded next to nothing of archeological importance. Lund tried out more than 800 caves in Brazil alone, of which only 6 yielded traces of man, and those of doubtful antiquity. The West Indian caves have supplied similarly uncertain results.[58] In Yucatan numerous caves have been excavated by Thompson, Mercer, and others, with even less of promise.[59] When we come to the United States the situation is no clearer, although protracted investigations have been carried out in practically all sections of the country where the topographic relief affords opportunity for caves and rock-shelters.[60] The number of possible sites thus tried out is not definitely known, but it must exceed at least 2,000, probably 3,000. In the way of returns for all this labor—unless the Gypsum Cave proves something really unusual—what have we? Merely this: Wherever culture debris has occurred in quantity there have been no positive traces of Pleistocene fauna; and, contrariwise, wherever Pleistocene fossil fauna has been found in quantity there have been no positive indications of man. And what is true for our cave deposits is true also for our out-of-door sites. The Princeton expedition to Argentina labored for 3 years in vain, so far as early man was

[56] Myers, J. L., Cambridge ancient history, vol. 1, p. 48.

[57] Rivet, P., Bulls. et Mêms. Soc. Anthrop., 5th ser., vol. 9, p. 209, Paris, 1908; Journ. Soc. Américanistes de Paris, vols. 6–8, p. 147, 1909–11.

[58] Harrington, M. R., Cuba before Columbus. Indian Notes and Monogr., Mus. Amer. Ind., Heye Foundation, New York, 1921.

[59] Thompson, E. H., Cave of Loltun, Yucatan, Peabody Mus. Mem., vol. 1, no. 2, pp. 1–24, 1897; Mercer, H. C., The hill caves of Yucatan, Philadelphia, 1896.

[60] Cresson, H. T., Early man in the Delaware valley, Proc. Boston Soc. Nat. Hist., vol. 24, pp. 145, 147, 1890; Mercer, H. C., Publ. Univ. Pennsylvania, vol. 6, pp. 139–147 and 149–178, 1897; Proc. Acad. Nat. Sci. Philadelphia, 1895; Schrabisch, Max, Archæology of Delaware River valley, vol. 1, 1930; Brown, B., The Conard Fissure, Arkansas, Mem. Amer. Mus. Nat. Hist., vol. 9, pt. 4, pp. 157–208, 1908; Merriam, J. C., Recent cave exploration in California, Amer. Anthrop., n.s., vol. 8, no. 2, 1906.

concerned; and the Field Museum expedition to the same country and to Bolivia searched for 5 years, collecting about 3,000 fossil specimens, among which was not a single item suggesting the presence of man during Pleistocene times. Consider also the famous Quaternary bone bed at the Rancho de la Brea oil-seep in southern California. Its investigation by paleontologists extends over about 30 years, and during that time the bones of more than 4,000 individual animals have been taken out. The majority of the species found are carnivores, but grass-eating animals, including the horse, bison, camel, elephant, etc., total at least 9 percent of the whole,[61] yet not only have no convincingly ancient remains of man himself been removed, but no spear points or other forms of weapons have been found, as might reasonably be expected, either stuck fast in the bones or lying loosely among them, as evidence that some of the animals had at times been attacked by hunters.

Compare this fact of all but uniform sterility in the New World with the diametrically opposite conditions obtaining in the Old World. In Europe alone more than 275 cave and open-air stations have been excavated which show the more or less constant repetition of associated fossilized human and animal remains of Pleistocene date. Additional sites demonstrating the same phenomenon could be listed also for Asia and Africa. But we must drop the subject at this point, allowing it to speak for itself.

General negative indications.—There are other alleged facts which seem to militate against the antiquity of man in America. It has been argued, for example, that the relatively greater number of iron meteorites found in the Western Hemisphere goes to show that those of the Eastern Hemisphere were largely used up by early man, as a natural consequence of his longer occupation of that region. The recorded proportions are 79 to 182 in favor of America; while for stone meteorites the conditions are reversed, the figures being 74 to 299 in favor of the Old World.[62]

Lastly, it is in order to remark that the complete distribution of the Paleolithic culture in the Old World is not yet a confirmed fact. Until very recently Ireland was regarded as outside the range—and may yet be. The same seems to be true also for the Philippine and other Pacific island groups, for Japan, and, as far as positive information goes, for northeastern Siberia. In these circumstances, even though it now appears that parts of Alaska were habitable during the Pleistocene,[63] we may well restrain our expectations concerning the American continent.

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[61] Loomis, F. B., American year book, p. 705, 1930.
[62] Rickard, T. A., Iron in antiquity, p. 12, Iron and Steel Institute, London, 1929.
[63] Frick, C., Nat. Hist., vol. 30, no. 1, pp. 71–80, Jan.–Feb., 1930.

CRITICAL COMPARISONS

Having dallied so long over the alleged facts bearing on our antiquity problem, there is little space left for critical comment on the situation as finally developed. The principal aim so far has been to make clear, if possible, that there are sound reasons for the long standing disagreement between archeologists and paleontologists. For the archeologist now to attempt an explanation of this disagreement and to put the paleontologist right is doubtless presumptuous, yet the temptation is strong. To the present writer the difficulty seems to inhere in their two distinct avenues of approach to the problem. The archeologist, who advances on the human prehistory enigma from the historian's point of view, is bound to have narrow and rigid ideas with respect to questions of time. The paleontologist, on the other hand, because he approaches the same enigma from the geologic point of view, has naturally shown himself rather generous in his ideas about time. It could scarcely be otherwise; to the historian time is limited, yet of first importance; to the geologist it is practically unlimited and, it seems, of secondary importance. The paleontologists and archeologists, in short, approach the same problem from opposite poles, as it were, and, therefore, their disagreements may well amount to nothing more than misunderstandings.

As the writer sees it, both the paleontologist and the archeologist are seeking to establish first of all relative chronologies and later, if possible, absolute chronologies. So long as these chronologies remain relative, all is well. Serious occasion for dispute does not arise until either side attempts to express the results in terms of actual time duration. The paleontologist, relying supposedly on what appears to be the uniformly slow evolution of biologic phenomena, is apt to stretch out his time factor, while the archeologist, impressed with the occasionally swift developments of cultural phenomena, is likely to underestimate the time element. Moreover, the two realms, cultural and biological, are not quite comparable; psychic and social factors play a greater part in the one than in the other; besides, the various factors entering into cultural developments are possibly better understood than are those regulating biological evolution. In the circumstances we can do no better than to look at the general permanence of results achieved by the two modes of approach, limiting ourselves, of course, to the data in which the two branches of investigation have a common interest.

When we review the joint labors of paleontologists and archeologists, insofar as they relate to discoveries made in stratified culture deposits, there is general agreement. The cave relics, e. g., of Europe,

leave no question as to the contemporaneity of man and of extinct animal species. The fossil remains in these accumulations were not re-sorted, as happens in open-air sites, and thus could give no erroneous ideas as to contemporaneity; besides, the associated items were found times without number in many different places, and they stand further chances of being verified over and over again. Nobody questions the conclusions arrived at from this source, except now and then as to absolute dates.

By contrast, the results are very different when we turn to the isolated discoveries made in the geologic deposits. And this is true not only with respect to New World finds but for Old World discoveries as well. As examples of the uncertainty regarding the age of such finds, it may be cited that the *Pithecanthropus erectus* remains, which for a long time were considered of Tertiary origin, are now generally regarded as of Quaternary date; the classic Paleolithic implement discovery in 1797 by John Frere at Hoxne, in Suffolk, has been labored over by English investigators off and on ever since, and has in turn been declared as dating from "a very remote period", "Postglacial", "Interglacial", "Postglacial", and, last of all, "Second Interglacial",[64] and recently the beginning of the Lower Paleolithic culture stage—in spite of much allegedly specific evidence dating it from the Third Interglacial—has by Breuil been shifted back in time by what must amount to several hundred thousand years, viz, to the First Interglacial! After having listened in for 5 months in Mongolia on paleontological discussions, such date shiftings no longer frighten me; but to the ordinary tender-minded archeologist feats of that kind are extremely disconcerting, to say the least. It goes without saying that there were good and sufficient reasons for these and other changes of opinions; but it also goes to show that the precise age, either relative or absolute, of any given geologic deposit may be difficult, perhaps impossible, of exact determination. To the geologically minded, accustomed to deal with vast durations of time, such minor shiftings obviously mean very little; to the historically minded, reckoning events by single years, they mean a great deal. This is not, of course, to say that our isolated archeo-paleontological discoveries are no longer of great importance; it is merely to suggest that the final chronological position of such finds is in many instances an open question which should not worry us overmuch.

In conclusion, it may be of interest to compare the variously achieved archeological results of both the Old and the New Worlds, and to do it in such a way that they may readily speak for them-

[64] Moir, J. Reid, The silted-up Lake of Hoxne and its contained flint implements. Sladen Excavation Fund and British Asso. Rep., vol. 5, pt. 2, pp. 137–165, 1925.

selves. To that end the tabular scheme on opposite page is presented, which seeks to indicate at once the geographical sources and technological characteristics of the data and also their alleged geological dates.

Comment on the table is scarcely necessary, inasmuch as it does little more than sum up what has been previously considered. It is legitimate to remark, however, that the Old World column, though very likely subject to shortening at the lower end, presents a fairly natural, genetically related evolutionary series of implemental forms, which is all but completed within the range of the stratified "archeological deposits" themselves. The New World column by comparison is short, though consistent as far as carried by the archeological deposits, and beyond that distinctly erratic and incomplete. Some downward lengthening and rectification of the strictly archeological portion of the column is to be expected, but the section of the record falling within "geological deposits" seems beyond all hope of reconciliation either with itself or with the corresponding section of the Old World record.

SUMMARY AND CONCLUSIONS

An effort has been made in the foregoing pages to review the various aspects of the archeological problem presented by the native inhabitants of the American continent, with a view primarily of seeking an answer to the much disputed question of their antiquity. In approaching the task it has been frankly assumed that the physical and cultural characteristics of the New World peoples were not entirely unique and independent developments, but were to some extent intimately related to human life and culture of the Old World, and that, therefore, the best results could be achieved through constant comparison of the pertinent facts made available by research in the two hemispheres. The original peculiar fascination of the general American problem has been explained and the various steps in its formulation indicated, leading to the notion that so far as primary interest is concerned the old questions of origin and antiquity have today been largely superseded by the more immediate and practical question of cultural development. Next, a brief sketch of the actual course and accomplishment of American investigations has been introduced to supply the necessary basis for an appreciation of current archeological opinion. Finally, there has been presented in some detail the various types of New World evidence—ethnological, paleontological, and archeological—produced and adduced during the past century as having direct bearing on the antiquity problem; and this body of mostly concrete data has been compared and contrasted, as far as possible, with similar data recovered in

Comparative chart: Indicating the successive culture-levels and their alleged time and mode of occurrence in both the Old and New Worlds

Geologic epochs	Old World culture-levels		New World culture-levels	
	Archeological deposits	Geologic deposits	Archeological deposits	Geologic deposits
Recent	Iron Age Bronze Age Copper Age Late Neolithic Early Neolithic	+	Bronze Age Copper Age Late Neolithic Early Neolithic	+
Post-Glacial or Holocene	Azilian-Tardenoisian	+		Neolithic and proto-Neolithic (N. J., Fla., Minn., Nebr., Tex.(?), N. Mex., Colo., Nev.)
Glacial, Quaternary, or Pleistocene.	Magdalenian Solutrean Aurignacian Mousterian (cold) Mousterian (warm) Acheulian Chellean	+		Alleged: Neolithic (Argentina, U. S.) Paleolithic (Trenton, etc., U. S. A.)
Pliocene		Alleged: Pre-Chellean (England, France) Eolithic (England, Egypt, Burma, etc.)		Neolithic (California)
Miocene		Eolithic (France, Portugal)		Neolithic (California) Eolithic (Patagonia)
Oligocene		Eolithic (France, Belgium)		Eolithic (Patagonia)
Eocene		Eolithic (?) (France)		Eolithic (Patagonia)

the Old World. These comparisons have revealed America's strictly archeological record as broadly conformative, but at the same time decidedly brief; while our supplementary paleontologic contributions, derived from geologic sources, appear as both genetically or typologically incomplete, as well as absurdly misplaced and irregular in their stratigraphic occurrences.

As to precise conclusions regarding the antiquity of man in America, it is scarcely necessary to say that the time has not quite arrived for their formulation. It is agreed on all sides that Lubbock's "3,000 years" or Nadaillac's "3,500 years" are insufficient to account for all that was accomplished in the prehistoric New World; but how much more time should be allowed, in the light of the rate at which the successive cultures developed in the Old World, can at present be little better than a guess. However, taking into consideration all the facts set forth, the only conclusion that now seems warranted is that man did not reach the American continent until some time after, but probably incidental to, the general disruption caused by the last ice-retreat, and that he came as the bearer of the partially developed Neolithic culture, somewhere between 5,000 and 10,000 years ago. If, on paleontological grounds, more time than this must be granted, then—in keeping with the suggestion made in Natural History in 1919—the most that the archeologist can concede at present is that possibly we have in America very faint traces of the Solutrean culture stage, of which the Folsom, N. Mex., discovery may be an example. But even this admission still leaves the antiquity of man in America as essentially postglacial.

A SURVEY OF SOUTHWESTERN ARCHEOLOGY[1]

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[With 9 plates]

Southwestern archeology has long occupied a prominent place in North American anthropological researches, but at no time since investigations were started has there been as wide-spread an interest or so marked a diversity of effort in the area as that of today. Intensive studies and numerous conferences have produced so much material that it is difficult for those not directly concerned with the field to keep abreast of its developments. Several articles, reports, and books appearing in recent months review the archeology of the region in an effort to explain the present status of the subject. There is still some misconception, however, about various phases of the problem, and a number of features, particularly earlier contributions, have been so consistently overlooked that an additional résumé may not be out of place.

Early Spanish explorers observed and recorded ruins which lay along their routes of travel, but it was not until the middle of the nineteenth century that the remains began to receive serious attention. Members of the various military and survey parties of the westward expanding United States included in their official reports descriptions, plans, and drawings of the antiquities which they encountered. In fact, several of the major expeditions had men assigned to that phase of the explorations. As a result considerable interest was aroused in the subject, and definite steps were taken to place the governmental researches on a sound basis by consolidating them and putting them under the direction of the Smithsonian Institution. Universities, museums, and foreign investigators were attracted to the field, and private individuals organized expeditions to hunt for "relics" both for their personal curio cabinets and to sell. From that time onward there has been an ever-increasing zeal on the part of diggers. When the eastern

[1] Reprinted, by permission, with some revision, omissions, and the addition of illustrations, from the American Anthropologist, vol. 37, no. 1, January–March 1935.

tourists "discovered" the Pueblo country a decade ago, the Southwest became archeology conscious and began to capitalize its antiquities. Local schools and colleges introduced courses on the subject in their curricula, and small societies and roadside museums sprang up all over the region. Whereas in former years most of the excavations were conducted by large institutions located outside the area, the regional organizations are now doing their full share. During the winter and spring of 1933–34 the landscape literally swarmed with "archeologists" sponsored by the Civil Works Administration, and in the following summer and autumn the activity continued under the Federal Emergency Relief Administration and other relief employment agencies. The results of this work are still to be determined, although consensus is that, with a few exceptions, the investigations were not as scientifically satisfactory as could be desired.

Hundreds of articles and reports have been written, and today there is an imposing body of literature on the subject. Many of the papers are excellent, others indifferent, and some should never have attained to the dignity of print. On the other hand, much work has been done which was never reported. Unfortunately some of the most important excavations ever carried on fall in this category. The publications fall roughly into three main classes: Graphic accounts of the superficial features of greater and lesser antiquities; detailed studies of buildings and objects found, with considerable emphasis on the function and symbolism of the latter; and comprehensive treatises on specifically planned investigations in an attempt to fit the data into their proper position in the historical pattern and to show what part they played in the course of cultural development in the area. The style of report correlates roughly with the series of years in which the work was done. The first belongs to the era of exploration, 1850 to 1880; the second to the interval of promiscuous digging with specimens as the chief incentive, 1880 to 1910; and the last to the period of excavations carefully planned with a view to solving recognized problems, 1910 to the present. This grouping may be criticized on the grounds that a few of the earlier men did endeavor to see the picture as a whole, while some now engaged in researches seemingly do not recognize that there is more to the problem than their own little projects. But, taken by and large, the three-phase classification does indicate what the trends have been.

That all of the ruins were not contemporaneous was suggested by various factors. Yet, although there was a broad classification of modern and pre-Spanish ruins, little attempt was made to determine sequential distinctions between sites until about 1910. Prevailing opinion was that no such differences could be ascertained for the pre-

Spanish group. This belief was strengthened by the unsatisfactory results which most of the workers obtained when they endeavored to develop a sequence on the basis of legendary evidence, by comparisons between artifacts, and by the state of preservation of the ruins.

For some reason stratigraphy was largely disregarded despite the fact that it had long proved extremely useful in Old World archeology. Not a few investigators held, and students were taught, that there could be no stratigraphy in the Southwest because the remains were only those of a single people, the Indians.

Stratigraphy was recognized in a few cases as indicating relative dates for material, but it was not until the present phase of southwestern researches that it received due consideration as an important source of evidence. N. C. Nelson, of the American Museum of Natural History, demonstrated the validity of the method when, beginning in 1912, he used it in New Mexico. He, as well as other field men, had recognized variations in the kinds and styles of pottery associated with ruins and village sites and believed that these differences had definite significance beyond that of merely being characteristic of the places where they were found. Accordingly, he chose a number of ruins known to be inhabited pueblos during the early Spanish occupation. By working downward from top to bottom in the adjacent refuse heaps, he determined the sequence of the principal pottery types of the Rio Grande region and in consequence the main chronological periods for the district.[2] At about the same time Kidder and Guernsey were using stratigraphy to establish the relative ages of several types of remains in the Kayenta district in northeastern Arizona, and Morris was applying the principle to his excavations at the Aztec Ruin in northern New Mexico. Subsequent projects, Hodge at Hawikuh, Kidder at Pecos, Judd in the Chaco Canyon, were conducted with a full consideration of the importance of this kind of evidence. Since that time stratigraphy has become one of the accepted routines in the technique of excavation.

To aid him in the study of his material Nelson developed a system of tabulations and percentages which not only showed the fluctuations in the pottery from a single site, but which proved of value in making comparisons between the types found at various ruins. Kidder employed an adaptation of the method at Pecos,[3] Kroeber used it successfully in the Zuñi region,[4] and Spier obtained excellent results in a survey of the Zuñi and Little Colorado districts by following an elaborated form of it.[5] Briefly stated, the technique makes possible a relative dating of sites on the basis of the percentages of the

[2] Nelson, 1916.
[3] Kidder, M. A., and A. V., 1917.
[4] Kroeber, 1916.
[5] Spier, 1917, 1918.

different kinds of pottery represented at each, provided the ceramic sequence has previously been determined by stratigraphy. The method was used for some time with good success. Recently, however, it has fallen into the discard. Just why this should be the case is not apparent. It is true that under certain conditions it is not an infallible source of evidence, particularly in chronological studies based solely on surface material. Nevertheless it is helpful in outlining the main characteristics of a district and in indicating where intensive work should be undertaken. In a consideration of the ceramics of a single site it has more than enough merit to warrant its retention in archeological procedure. By this means it is possible to demonstrate in a graphic way the true nature of the pottery complex. Perhaps one explanation for the failure to make use of the system is that the workers have become so absorbed in a detailed study of pottery per se—the writer has been guilty of such on occasion—in a determination of types and the finding of names for them, that they have forgotten the important factor of giving percentages. It is only from such data that the real significance of each group in the series can be judged.

Accumulated data had demonstrated that there were regional variations and that characteristic elements tended to conform to distinct patterns or styles according to the district in which they were found. Also, it was observed that the stylistic complexes seemed to radiate from particular centers and that they mingled or overlapped along the hazy boundary lines separating the numerous spheres of influence. In addition it was definitely established that there were a number of different stages or horizons in the unfolding of the culture. Although writers described these features, little attempt was made to combine the knowledge into a coherent whole until Nelson undertook a chonological study of the entire area. He had drawn up a diagrammatic chart to illustrate his conception of the relations between the various groups, as well as their origins, but had not completed his work when his efforts were diverted to other fields.[6] Nelson's outline broadened the viewpoint of students to a considerable degree. Even so, the possibilities for revealing a vivid and fascinating narrative of culture growth were not fully appreciated until Kidder published his Introduction to Southwestern Archeology in 1924. Kidder not only assembled, digested, condensed, and made available the salient facts of the existing data; he went further and correlated the mass of information into an historical reconstruction presenting for the first time a comprehensive postulation of developments in the area. The book had greater value, however, than that of summing up and interpreting the work which

[6] Nelson, 1919, p. 119.

had been done. It pointed out blank spots in the record, indicated clearly the districts where investigations were needed, and centered attention on a number of general problems previously overlooked.

Within the last decade a new method of obtaining chronological evidence, one making possible absolute rather than relative dating, was developed. This contribution came, not from an archeologist, but from an astronomer.

Dr. A. E. Douglass, of the University of Arizona, in making a study of sun spots and their effects on climatic conditions in the Southwest, turned to the growth rings of trees in an effort to obtain evidence on the occurrence of drought periods and the intervals of moisture. In doing this he discovered that the rings formed definite patterns by groups of years, and as a consequence he developed a system whereby he could tell whether the trees from which logs were cut were growing at the same time or to what degree their life cycles overlapped. Beginning with trees whose cutting date was known, he has been able to devise a type chart going back to about 700 A. D.[7] In obtaining evidence to substantiate his own theories he was forced to resort to timbers from ruins for material antedating living trees, and thus furnished the archeologists with an extremely valuable time scale. Now when beams are found in a ruin it is possible to check their rings with the historical chart and, provided the outer surfaces have not been damaged or removed, tell the year of their cutting. Of course, the timber may not have been placed in the structure immediately after the tree was felled, and occasionally a log was no doubt reused. It is possible though, to gage the results by a careful consideration of the archeological aspects of the site, and a date is assured which closely approximates the year or years when the dwellings were erected.

Continued work with the tree-ring dating system, or dendrochronology, as it is now called, demonstrated that the type chart would not function in all cases. Material from some sections did not correlate properly because of local variations in characteristic ring patterns. For this reason it has been necessary to develop supplementary charts. This work is being carried on by a number of Dr. Douglass' students, and newly dated ruins are constantly being added to an already sizable list. Rivalry between workers to find earlier and earlier dates has in one or two instances caused misunderstandings. Correct use of the system requires that the announced date should be the outermost ring in the timber. Occasionally the date of the earliest discernible ring has been proclaimed in such an ambiguous way that the implication was that that was the year when the log was cut and the building erected. One such case led to

[7] Douglass, 1935.

numerous newspaper and magazine articles attributing approximately 200 years' greater antiquity to one major ruin than it actually possesses. This not only created an entirely erroneous idea about the age of the site, but it gave rise to considerable confusion, since nearby structures believed to be contemporaneous, on the basis of archeological evidence, had yielded much later dates. Peculiar inconsistencies in some recent identifications and interpretations of material have led a number of those specializing in dendrochronology to formulate an agreement to the effect that each date, as well as the specimen upon which it is based, be examined and approved by Dr. Douglass before it is released for publication. There is no question but that great care should be taken. The results so definitely fix a ruin's position in the chronology that an inaccuracy might wholly obscure the actual course of events in a region.

One gratifying feature about the tree-ring dating is that the results have checked with the findings obtained from other sources of evidence. Prior to the perfection of the system the relative ages of a number of large ruins and village sites, even of remains in different districts, had been worked out by archeological methods. When dendrochronological dates became available, it was noted that the conclusions reached previously had been correct, although the estimated time lapses had been much too great.

As a result of the stimulation of interest produced by Kidder's book, the entrance into the field of numerous new workers not wholly familiar with existing conditions, an increase in published material, and a growing confusion in the correlation of information, it became apparent that something should be done to improve the situation. Accordingly, Dr. Kidder invited the workers in southwestern archeology and related fields to meet in informal conference at the Phillips Academy, Andover, excavation camp at Pecos, N. Mex., on August 29–31, 1927. The 3 days of discussion led to an agreement on a series of sequent stages in the culture growth and a set of names designating the several phases, the Pecos Classification, was adopted. This conference was so satisfactory to most of the workers that many of them again met at Pecos in the summer of 1929. The sessions of the second gathering were devoted mainly to a review of the original classification and to reports on excavations conducted subsequent to the first conference.

Most of those attending the second conference expressed the belief that the classification had been of help to them in their studies. Some stated that they had had difficulty in applying the various criteria. This was especially true for one definite region. Consideration of this perplexity served to emphasize a fact which had been becoming more and more apparent, namely, that the remains in the southern and western portions of the area, the desert domain, are not Puebloan

in type. Cosmos Mindeleff commented on this difference in 1896 and suggested that it was too marked to be attributed wholly to a question of environment.[8] Kidder, in 1915, separated southwestern culture into two major divisions on the strength of the dissimilarities,[9] and again pointed them out in 1924. In the latter publication, however, with pottery as a criterion, he concluded that in some respects these aberrant sites were allied to the Pueblo ruins.[10] Nelson had recognized the distinction, and in 1919 indicated it on his diagrammatic chart, although he did not give a detailed discussion of the problem. The situation was not accorded the attention which it merited—actually was overlooked at the first conference—until Gladwin and others working in the district, beginning in 1927 and continuing through subsequent years, obtained definite evidence that the types were different. The full import of this did not crystallize at Pecos but at Gila Pueblo, Globe, Ariz., in April 1931, when a classification was drawn up for that division by workers interested in its problems. The results of the Gila Pueblo conference were presented to a larger group of southwestern students at the Laboratory of Anthropology at Santa Fe, N. Mex., in September of that year. The Santa Fe session, which took the place of the biennial Pecos conference in 1931, discussed and adopted the Globe recommendations. There have been no general meetings of that nature since.

From the knowledge amassed during the many years of investigations and on the basis of understandings reached in various conferences, most southwestern archeologists today synthesize the data broadly and briefly as follows: Scattered over the area are the remains of a basic sedentary, agricultural, pottery-making culture which has two major provinces comprising the plateau and desert patterns (fig. 1). The plateau division, which falls under the Pecos Classification, includes the regions of the San Juan, the Rio Grande, the Upper Gila and Salt, the Little Colorado, most of Utah, and a portion of eastern Nevada. The desert domain, summed up by the Globe Classification, occupies the territory extending from the Colorado River on the west to approximately the New Mexico line on the east, from Flagstaff, Ariz., on the north to northern Sonora on the south, with its center lying in the middle Gila Basin. The northern boundary follows roughly the thirty-fifth parallel from the Colorado, swings slightly north to include the Flagstaff section, thence southeastward across Arizona, conforming for the most part to the great diagonal ridge sometimes called the "Mogollon Rim" or the "Verde Breaks", and continues along the Gila Mountains as far as Safford, Ariz. The eastern boundary extends from Safford

[8] Mindeleff, C., 1896, pp. 186–187.
[9] Kidder, 1917.
[10] Kidder, 1924, pp. 105–106, 107.

southwestward to the San Pedro Valley and on to the Santa Cruz Valley south of Tucson. There is, of course, an overlapping of the patterns in the border precincts, but only in late phases is there any indication of fusion. In only one district, the Verde Valley, do the two appear to have coalesced to form a subpattern.

The Mogollon district (fig. 1), hitherto thought to represent a regional variation of the Basket Maker-Pueblo pattern, is now tenta-

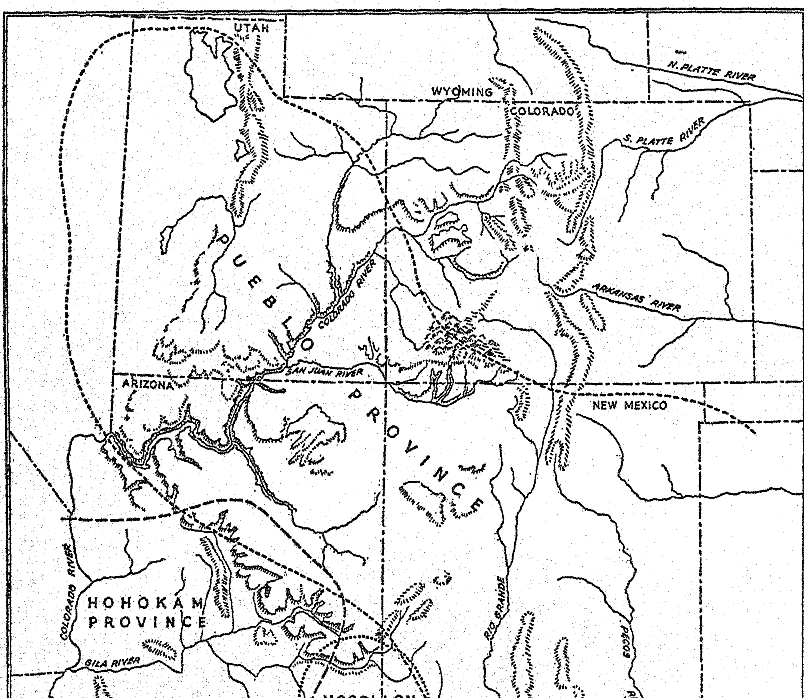

FIGURE 1.—Sketch map of southwestern area showing location of main cultural provinces.

tively considered a distinct subpattern by Dr. Haury of Gila Pueblo. Until reports on Dr. Haury's investigations are available, however, it is not possible to evaluate the material.

The plateau group is designated by the long familiar names, Basket Maker-Pueblo, while the desert dwellers have been termed the "Hohokam", a word used by the Pima when they make reference to the ancient ones. Russell employed it in an archeological sense when he referred to the ruins and antiquities of the region in his monograph on the Pima. It was not adopted or generally used,

however, until after the meeting at Gila Pueblo. The Hohokam for a number of years went under the working designation of the Red-on-Buff Culture because of the color characteristics of its pottery. In considering the two major divisions the Basket Maker-Pueblo with its so-called "Pecos Classification" will be discussed first.

BASKET MAKER-PUEBLO

The uplands pattern is recognized as representing a cultural unit with several horizons in its development. The general view is that agriculture, introduced from the south, was taken up by a nomadic people whose newly acquired economic factor led to a more settled life. At a later date pottery making was either introduced or invented, and houses of the pit type were perfected. This was accompanied by changes in existing elements in the material culture and the appearance of other features. New peoples then invaded the region; dwellings were built above ground and evolved into many-roomed structures. With the infusion of new blood there was an acceleration in the unfolding of the cultural pattern. Small villages were scattered over a greater part of the uplands province. Later there was a contraction in the extent of occupied territory and a concentration of population into definite centers. This phenomenon was accompanied by improvements in architecture and the ceramic arts together with pronounced local specialization. Following this stage there was an even greater shrinkage in occupied territory, a shift to new localities, and a decline from the preceding cultural peak. This stage was terminated by the arrival of the Spaniards and subsequent colonization by other white men.

The first Pecos conference grouped the various horizons under two main headings, Basket Maker and Pueblo, which were further divided into subgroups. Hence the Basket Maker I, or Early Basket Maker; Basket Maker II, or Basket Maker; Basket Maker III, Late Basket Maker, or Post-Basket Maker; Pueblo I, or Proto-Pueblo; Pueblo II; Pueblo III, or Great Period; Pueblo IV, or Proto-Historic; Pueblo V, or Historic. These eight steps or stages in the development of the general pattern were based on several diagnostic traits. For the two major groups skeletal material was considered significant. In the material culture the following elements were believed indicative of the various stages; village types, architecture, sandals, pictographs, textiles, stone and bone implements, kinds and styles of ornaments, and pottery. Pottery, it was agreed, furnished the most abundant, convenient, and reliable criterion, and the culinary vessels the simplest ware for chronological determinations. Primarily the classification rests upon ceramics. One explanation

for this is that pottery is plentiful and readily obtained without the expenditure of any great amount of effort or money. It is characterized by easily recognizable differences in style and form and was an exceedingly sensitive element from the standpoint of variations both in time and place. Furthermore, when the first conference was held, little was known about the houses and still less about other factors for some of the early stages. The original summarized classification has been so widely published that it need not be repeated in detail.[11]

For the benefit of those not thoroughly familiar with the subject a brief consideration of certain elements in each horizon may help to an understanding of the sequence. This summary includes not only the material available when the nomenclature was adopted, but data obtained since 1927 as well. Discussion of all of the components of the complex for each subdivision is beyond the scope of the present article, so only a few traits will be described. Since Basket Maker I is only postulated, there is little to be said concerning it. Theoretically it was a nonagricultural stage possessing in cruder, less developed form some of the elements present in later levels. Actually no traces of it have been found. A number of the discoveries made in recent years which indicate human occupancy of the area at a comparatively remote date cannot be considered, on present evidence, to represent the initial stage of the classification. These finds, Folsom,[12] Gypsum Cave,[13] etc., thus far have not been shown to bear any relationship to the Basket Maker. The most significant factor in this connection was the recent discovery by Dr. E. B. Howard of a Folsom type point in a level underlying a Basket Maker horizon.[14] This evidence indicates that the Folsom group was in the region earlier than the Basket Makers.

CRANIA

Basket Maker II, undeformed, long scaphoid. Basket Maker III, undeformed, long scaphoid; undeformed round (actually more mesocephalic than brachycephalic), are sometimes found in late sites. Pueblo I, deformed, both long and round. Pueblo II, deformed, round in the majority but an occasional long is noted. Pueblo III, deformed, preponderantly round, sporadic long. Pueblo IV, deformed, mostly round, few long. Pueblo V, deformed round and long. Undeformed round, occasional undeformed long.

SANDALS [15]

Basket Maker II, square toe with fringe, twined, woven of fine cord. Basket Maker III, scalloped toe, woven of fine string, design in color on upper side, woven pattern on under. Pueblo I, round toe, woven of fine string, coarse

[11] Kidder, 1927; 1931, pp. 5–6: Roberts, 1929, pp. 3–7.
[12] Roberts, 1935.
[13] Harrington, 1933.
[14] Howard, 1935, p. 78.
[15] Guernsey and Kidder, 1921; Guernsey, 1931.

pattern on under side. Pueblo II, round toe. Pueblo III, notched toe, woven of fine string and yucca leaf; square toe, yucca leaf, twilled weave. Pueblo IV, notched toe, string and yucca leaf. Pueblo V, moccasins.

BASKETRY [16]

Basket Maker II, loose weave, coiled, rod and bundle type, decorated in black or red. Basket Maker III, coiled, rod and bundle type, no difference either in technique or appearance from Basket Maker II; specimens are occasionally noted exhibiting an irregular splitting of the stitches. Pueblo I, coiled, rod and bundle, elaborate designs, twilled ring baskets. Pueblo II, twilled ring baskets, two rod and bundle coiled; general lack of information, however. Pueblo III, some coiled, rod and bundle with fine tight weave but no design, twilled ring baskets numerous. Pueblo IV, same as for Pueblo III. Pueblo V, baskets of plaited yucca leaves attached to a wooden rim, coiled rod and bundle baskets and trays, wicker-work baskets.

TEXTILES [17]

Basket Maker II, twined-woven bags with designs in color, finely woven from apocynum-fiber string; coiled-netted weave of human-hair string. Basket Maker III, twined-woven bags of coarse weave with no design; coiled-netted weave of coarse-fiber string. Pueblo I, cotton cloth. Pueblo II, cotton cloth. Pueblo III, cotton cloth of plain loom weave; elaborately decorated loom weave; netted weave. Pueblo IV, same as for Pueblo III. Pueblo V, cotton, wool, commercial items purchased from traders.

WEAPONS [18]

Basket Maker II, atlatl, grooved clubs. Basket Maker III, atlatl, grooved clubs, bow and arrow toward end of horizon. Pueblo I, bow and arrow. Pueblo II, bow and arrow. Pueblo III, bow and arrow, throwing club. Pueblo IV, bow and arrow, throwing club. Pueblo V, bow and arrow, throwing clubs, European weapons.

HOUSES

Basket Maker II, no information, possibly erected temporary shelters in the open. Dug into the floors of caves are circular or oval pits, in many cases lined with slabs of stone, which constituted lower portion of granaries. Now and then examples are found with pole, brush, and plaster superstructures still in position over pit. Occasionally these cists were lined with bark and grass and seem to have functioned as sleeping places.[19]

Basket Maker III, dwellings of the circular, oval, or rectangular pit variety. Excavations lined with upright stone slabs or heavy coating of mud plaster or both, sometimes a wainscoting of poles was used in place of stone. Roofed over with a conical or truncated superstructure of poles covered with mats or brush, plaster, and earth. Central smoke hole, side entrance passage, sometimes an antechamber. Granaries of Basket Maker III form clustered about the houses. Number of such dwellings irregularly grouped together to form a village.[20]

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[16] Guernsey and Kidder, 1921; Guernsey, 1931; Weltfish, 1932.
[17] Guernsey and Kidder, 1921; Kidder and Guernsey, 1919; Guernsey, 1931.
[18] Guernsey and Kidder, 1921; Guernsey, 1931.
[19] Guernsey and Kidder, 1921.
[20] Guernsey, 1931, pp. 25–27; Roberts, 1929, pp. 10–105.

Pueblo I, characterized by transitions in house types, variety of structures. In the north central section of the province, the portion traversed by the San Juan and its tributaries, the crude, single-roomed semisubterranean dwellings (pl. 1, fig. 1) gave way to structures which had only slightly depressed floors instead of pits. Major portion of house was above ground. Had several contiguous rooms. Pole and plaster form of construction, jacal walls, prevailed at first but was replaced in time by masonry (pl. 1, fig. 2). Pit domiciles continued in use in peripheral districts, especially in the south and west. Pits were dug deeper, however, and entrance to chambers was by means of a ladder through the smoke hole. In a few precincts the side entrance survived. Where entrance was through the roof the former side passage was retained in reduced size as a ventilator. Above ground villages retained a subterranean structure as a ceremonial house, the kiva.[21]

Pueblo II, unit-type structures or one-clan houses. These dwellings of stone or adobe, built entirely above ground, contained from 6 to 14 rooms (pl. 2). They were a single story in height with rooms grouped in one long row, a double tier, an L-shape or in the form of a rectangular U. Usually at the south or southeast side, detached from the building, was a subterranean ceremonial chamber.[22] In peripheral parts of the area this type of dwelling did not reach as high a degree of excellence. Pole and mud houses and irregular agglomerations of rooms whose walls were formed from large quantities of adobe mud and unworked boulders prevailed in the south and west. In the Flagstaff district rectangular pit dwellings survived through this horizon.[23]

Pueblo III, the great terraced communal houses of many rooms, mostly of stone construction, although adobe was sometimes used. Erected either in the open or in large natural caverns in the cliffs (pl. 3). Also, one-clan houses scattered about in the vicinity of the large centers. In some sections cavate dwellings, rooms cut into the soft tufa or cliff faces, were not uncommon.[24]

Pueblo IV, communal houses, scattered dwellings, cavate lodges.[25]

Pueblo V, villages of terraced houses (pl. 6), of one-storied single-family houses, scattered single-family dwellings. Numerous examples of this stage are known to the general public, Taos, Zuñi, Acoma, and the Hopi towns especially.

POTTERY

Basket Maker II, no true pottery but large containers of unfired clay tempered with cedar bast, the chaff of corn tassels, or grass heads. Molded in baskets or built up without aid of molds. Formed of horizontal bands of clay, the beginning of the coil technique.[26]

Basket Maker III, fired vessels. Light gray to a fairly good white in color; red containers; bowls with an unpolished black interior and gray exterior. Surfaces irregularly stippled in appearance, the result of protruding particles of tempering material. Sand or crushed rock temper, paste granular in cross section. Red ware due to an intentional overfiring, not to a colored slip. Bowls usually decorated on interior (pl. 4), other vessels unornamented.

[21] Kidder, 1924, pp. 74–75; Roberts, 1930, pp. 19–73; 1931, pp. 15–90.

[22] Prudden, 1903. These structures illustrate the form but are Pueblo III in horizon. A number of examples have been excavated in the Chaco range but the data are unpublished.

[23] Colton and Hargrave, 1933.

[24] The works of Fewkes, Pepper, Mindeleff, Hough, and numerous others illustrate this horizon. See bibliography in Kidder, 1924; also citations in Roberts, 1932, pp. 17–19.

[25] Roberts, 1932, pp. 20–21, for examples.

[26] Morris, 1927, pp. 138–160.

Designs are generally ribbonlike panels embellished with dots, zigzag and stepped line elements, occasional life-form figures. Decorations carried over from basketry to pottery. Most vessels treated, after firing, with a wash of red pigment. This is impermanent and has been called "fugitive red." Culinary vessels smooth on the exterior.[27]

Pueblo I, plain gray, black on white, lustrous black on red, slightly polished black interior bowls with brownish exterior. Introduction of slip. Tempering of white sand, ground rock, or pulverized potsherds. Decorations on all types of vessels. Main design elements consist of zigzag, parallel, parallel-stepped lines, and squiggled lines; filled triangles and dotted triangles; volutes and ticked volutes; interlocking frets; checkerboard; concentric rectilinear and curvilinear figures (pl. 4). Patterns taken from textiles in addition to baskets. Culinary vessels with corrugated necks, flat neck bands, and smooth bottoms (pl. 5). Period marked by great diversity of form. In the black on white ware there are two main groups, the eastern and western. Of course, there are many local minor variations, but for a general consideration the two main forms are sufficient. The eastern centered about the Chaco Canyon area and the western around the Kayenta district in northeastern Arizona. The eastern extends from the northeastern San Juan Basin in southern Colorado to the Upper Gila region in southern New Mexico, from the Rio Grande on the east to approximately the New Mexico-Arizona boundary line on the west. In the west its southern fringes penetrated somewhat into eastern Arizona. The western Pueblo I ranged from northeastern Arizona to the Little Colorado in the eastern part of the State, swung a bit south of that stream farther west, and continued across to southeastern Nevada. The eastern borders are not sharply defined, and there is a strip extending down the Arizona-New Mexico line where the two phases overlap. The western, or Kayenta black on white Pueblo I, was the first to be recognized and for a long time was thought to be the characteristic form. Later investigations in the Chaco Canyon and the northeastern San Juan Basin established the second, Chaco black on white Pueblo I, and what appears to be the most wide-spread division. The basic difference is twofold: Pigment and surface appearance. The Chaco form had an iron-carbon paint, the Kayenta a carbon. In the Chaco group the paint stands out from the slip, whereas in the Kayenta it seems to fade into the surface of the vessel. General appearances suggest that the potters of the Chaco style applied the pigment after the surface of the vessel was polished and those of the Kayenta "school" painted the decoration before the polishing process was completed. There is no difficulty in telling one from the other or in recognizing either as Pueblo I because the basic style of decoration is the same for both.[28] The culinary vessels, black on red and blackened interior bowls, are the same in the two divisions.

Pueblo II, gray ware, black on white, lustrous black on red, polished black interior bowls with reddish exterior. Ground rock tempering, some sand, powdered potsherds. Decorations on all kinds of vessels. Painted designs characterized by broad, heavy elements; some survival of Pueblo I features but without series of bordering parallel lines. Culinary vessels with indented corrugations on necks, smooth bottoms, or plain corrugation over entire surface. Indented corrugation large and coarse, frequently called "exuberant." Simple form of design pinched into corrugation or incised with finger nail or

[27] Morris, 1927, pp. 161–198; Roberts, 1929, pp. 107–126.

[28] Kidder, 1924, pp. 74–76, Kayenta or western (called pre-Pueblo).
Guernsey, 1931, pls. 59, 60, 61. Kayenta or western.
Roberts, 1930, pp. 74–139; 1931, pp. 114–149. Chaco or eastern.

implement (pl. 5). The beginning of spiral coil. In previous stages each loop of clay had made only a single circuit, while in Pueblo II longer fillets were employed and each made several turns around the wall.[29]

Pueblo III, gray ware, black on white, polychrome, black interior and red exterior, black on red. Late in period the beginning of black on yellow, black on orange. Fine texture, potsherd tempering as a rule. Designs characterized by elaborate detail and careful execution. The era of marked specialization. Pottery of various districts so typical that its place of origin may be recognized immediately, whether Mimbres, Chaco Canyon, Kayenta, etc. Culinary vessels covered over entire surface with finely indented corrugation. Continuous spiral coil in manufacture.[30]

Pueblo IV, plain gray, plain yellowish, black on white, black on red, black on yellow, black on orange, polychrome, glazed wares. Sand and potsherd tempering. Elaborate designs, solid, heavy elements. Break-down in corrugation on culinary vessels, beginning of return to smooth surfaced cooking pots[31] (pl. 5).

Pueblo V, modern painted wares of the Pueblos. Smooth surfaced culinary vessels[32] (pl. 5).

OTHER TRAITS

There are a number of traits which are more or less distinctive to one period or occur in several but which are not continuous through the pattern. Basket Maker II has tree-shell trowels or characteristic wooden scoops, peculiar lozenge-shaped beads, buttonhole stitch on selvage of plain-weave cloth. Basket Maker III a cross-stitch spindle and a unique type of small globular pottery vessel with a lateral spout. Basket Maker II–III have small funnel- or nipple-shaped unfired clay objects either plain or decorated with a punctate design; also clay figurines usually representing human females.[33] Basket Maker III and Pueblo I–II have the open-end trough metate or milling stone placed on the floor. Pueblo III–V flat metates set in bins. Pueblo I–V the domesticated turkey and the polished grooved-ax. Pueblo IV pottery with the designs in glaze.

There is always the possibility that something from an earlier phase will appear in one of the later stages. This may be a continuance, a revival of an older form such as took place in the Hopi country when Nampeo started a renaissance based on pottery from the Pueblo IV ruin of Sikyatki, or an actual survival of one or more objects from a previous horizon. Even among the Indians there are and were devotees of the "antique", and the archeologist occasionally stumbles upon a choice collection of objects which belonged to such a person. It should be evident that allowances must be made for occurrences of this kind but, as is so often the case, the obvious is so frequently overlooked that attention needs constantly be called to the fact that archeologically "once a thing has

[29] Guernsey, 1931, pls. 42, 43, 66; Hargrave, 1932, p. 12 Coconino gray, p. 14 Deadman's corrugated, p. 15 Deadman's black on white.

[30] Kidder, 1924, pp. 51–74; Cosgrove, 1932; Hargrave, 1932; Roberts, 1932, pp. 18–19 for additional references.

[31] Kidder, 1924, pp. 86–87, 1931; Hargrave, 1932; Roberts, 1932, pp. 20–21 for additional references.

[32] Bunzell, 1929; Kidder, 1931, pp. 131–150.

[33] Morris, 1927, pp. 154–158.

been, it will be again and again." It has been the failure to consider carefully such factors that has caused some students trouble in properly evaluating their finds.

As an illustration of the time element involved and in response to oft-repeated queries concerning the age of ruins, a number of writers have supplied dates for the various stages in the sequence. These were not an integral part of the Pecos Classification, with the exception of Pueblo V, and were not given with the idea of isolating each stage between arbitrarily chosen sets of years because there is no sharp break between periods. Insofar as possible, these dates were based on information furnished by dendrochronology. For the earlier stages, however, data from this source were not available and the figures were speculative. Most reports stressed this factor and pointed out that there could be no hard and fast application of the numerical chronology. A tendency has developed in certain quarters to make these dates the horizon determinant and ignore all the elements in the complex. A bare numerical tabulation is not sufficient to make clear all of the ramifications of peripheral lags and stage survivals.

There are two peripheral precincts where the Basket Maker-Pueblo pattern is not clear cut. In these outlying reaches many features, common in the nuclear districts, are missing. On the other hand, local developments have contributed elements which are foreign to the central portions. These marginal regions are generally designated as the "northern and eastern peripheries." The northern comprises the territory north and west of the Colorado River, ranging along the western slopes of the Rocky Mountains into southern Idaho and extending westward into eastern Nevada. The eastern includes the country lying to the east of the Rio Grande drainage and extends from the Oklahoma panhandle on the north through western Texas to the Big Bend district on the south. The western and eastern boundaries of the two peripheries, respectively, have not been determined.

The northern periphery is characterized by a progressive fading of the basic pattern in proportion to the distance from the central portions of the province. The general nature of the remains indicates a Basket Maker III–Pueblo I origin for a complex which has distinctive qualities resulting from a combination of factors. Among these may be noted the survival of early elements, varying rates of diffusion for important features in the main pattern, the synchronous appearance of components which were chronologically distinct in the nuclear districts, the adaptation of borrowed features to local needs, and inventions. Except for a narrow strip along the Colorado River in the southern part of the periphery where the pattern was closely

allied to that of northern Arizona, the grooved ax, the grooved maul, sandals, and the domesticated turkey, cotton, and various pottery forms are missing from the complex. Local features rare or absent in the central phases are a peculiar type of moccasin called the "Fremont", unbaked-clay figurines in late horizons, the Utah type metate, katcina-like petroglyphs, and pottery ornamented with certain kinds of applique decorations. In the outer fringes of the periphery the Basket Maker–Pueblo pattern came to an end, owing in large part to pressure from hostile nomadic peoples, at approximately the termination of Pueblo II in the main part of the province. Along the Colorado River it continued well into the Pueblo III horizon.[34]

The general features of the eastern periphery, except for the Pecos district, are not as well known as those of the northern periphery. The Pecos ruins, located on the headwaters of the Pecos River, represent the largest eastern outpost of the Pueblo country and, although topographically not of the Rio Grande group, are so considered because of their obvious relationship to the remains of the Santa Fe region. The Pecos ruins proper, as well as the smaller sites in the vicinity, have been thoroughly studied by Kidder and his associates, and considerable data are available on them. The presence of ruins farther east from the Pueblo country has been known since the days of Bandelier in the late eighties, yet little attention has been paid to them until the last few years. Eastward from the Rio Grande drainage small sites with black on white pottery occur almost to the Texas border. Along the Cimarron in Oklahoma are caves from which material suggestive of the Basket Makers has come.[35] Basket Maker finds have been made in the Guadalupe Mountains in southeastern New Mexico,[36] and caves in the Big Bend district of western Texas have yielded elements comparable in some respects to the Basket Maker.[37] In the Canadian River district of eastern New Mexico and western Texas are the remains of villages which until recently were considered the eastern frontier of the Pueblos. The houses were of stone construction and varied in size from single-roomed circular or oval or rectangular structures to large buildings with numerous chambers of varying sizes and shapes. Because of the crude nature of potsherds found at the small sites, they have frequently been identified as Basket Maker III or Pueblo I. As a matter of fact, the pottery is of the plains type, and the occasional Pueblo fragment found is intrusive. The larger ruins have yielded Pueblo potsherds which indicate a Pueblo IV horizon. The general consensus is that these

[34] Steward, 1933.
[35] Renaud, 1930.
[36] Howard, 1935.
[37] Setzler, 1933.

sites represent the western fringes of an eastern cultural pattern which borrowed Pueblo architecture.[38] On the whole, the Pueblo remains of the eastern periphery probably do not antedate Pueblo III of the nuclear districts nor postdate the first part of Pueblo IV.

THE HOHOKAM

The Hohokam or desert province is not as well known as that of the Basket Maker-Pueblo because intensive work in the remains of that division is only just beginning. Efforts of investigators have produced good results in the last 5 years, and considerable information is now available, but there is as yet nothing comparable to the mass of data concerning the uplands province. From what has been learned it is apparent that the desert pattern represents a cultural unit with several developmental stages. Contrary to the Basket Maker-Pueblo, which is considered largely indigenous in its growth, the Hohokam is thought to have entered the Southwest as an already established pattern, although it continued to evolve in its new locale. The earliest stage is characterized by a widespread distribution of small villages situated in the broad semiarid valleys of the province. This was followed by a horizon in which there was a greater concentration and a withdrawal from the more outlying precincts. Then there was an invasion of peoples from the uplands, and typical pueblos were built in Hohokam communities. The two peoples lived side by side, apparently, yet kept their cultural patterns distinct, the association seemingly being of insufficient duration for a borrowing or hybridization of characteristics. The northern people then withdrew from the area, while the Hohokam continued to occupy their long-established hearths. Comparative studies between dated sites of the group which penetrated the desert domain and then withdraw and materials which they left in the Hohokam province place the movements between 1300–50 and 1400–50 A. D.[39] It is postulated that the Hohokam eventually evolved into the Pima and Papago, although this is still a moot question, and a number of ethnologists are outspoken against such a theory.

General characteristics of the Hohokam are: Dwellings of the single-unit type, rectangular in form; agriculture dependent upon extensive irrigation systems; paddle and anvil pottery; cremation of the dead; head form believed to be long and undeformed (this point doubtful because of cremations). The refinement of the pattern has been grouped under 6 horizons which are roughly synchronous with the 8 in the Pueblo province, the earliest Hohokam

[38] Holden, 1932.
[39] Gladwin, 1935, p. 254.

stage possibly correlating with Basket Maker II and III. As in the case of the Pecos sequence, the Globe Classification rests primarily on pottery. The nomenclature lists the stages as: The Pioneer, the Colonial, the Sedentary, the Classic, the Recent (listed as Degenerate in some reports but no longer so called), and the Modern. In making a brief summary of the various stage differences, only a few elements in the complex will be considered.

DISPOSAL OF THE DEAD

Pioneer, pit and trench cremation. Colonial, pit cremation. Sedentary, urn cremation. Classic, urn cremation, inhumation (Pueblo). Recent, cremation. Modern, inhumation.

HOUSES

Pioneer: Very large at first (up to 40 feet) and square; then became smaller and rectangular, shallow pit, rounded ends, vestibule with rounded entrance on side. Colonial: Rectangular, shallow pit, vestibule entrance on side. In some cases the floor was raised above the bottom of the pit on stone posts. Walls of poles, brush, and mud plaster. Each dwelling a unit in the village.[40] Sedentary: Rectangular pit houses, rectangular surface houses with a framework of poles and grass, daubed with mud. (Pl. 7, b.) Villages enclosed in a compound wall.[41] Classic: Pit houses, one-story surface houses of poles, brush, and mud; multistoried communal buildings often referred to as temples, fortresses, or clan castles (Casa Grande, pl. 8, fig. 1), but which were essentially pueblos. The compound wall continued in use. Recent: Pole, brush, and clay houses and in some sections a combination of compound and pueblos. Modern: Pole, brush, and clay dwellings (pl. 8, fig. 2).

POTTERY

Pioneer: A thin plain ware and a red ware in the earliest phase, painted pottery being totally absent. When the latter appeared it was decorated with simple red patterns in broad lines, sometimes polished, on a buff to gray, unslipped background. Development in ornamentation produced several forms of hachured elements which preceded the style characteristic of the Colonial period. Some of the painted vessels, mainly bowls, were further embellished by a grooving of the exteriors. At first the grooves were deep and symmetrically placed, later they became shallow and irregular. Vessels are shallow bowls with outcurved sides, developing later into the flared bowl which became a dominant factor in the Colonial and Sedentary periods; and round-bodied jars with necks flaring into an open curve. The plain ware became thicker as the Pioneer stage progressed. The red ware was quite plentiful at first but became rare toward the end of the period. One type of ware, called San Francisco Red, seems to have penetrated into the province from the Mogollon district and may eventually be shown to have been related to the red ware of the Pioneer period. Elements used in the decorations on bowls and jars are very suggestive of those found in Pueblo designs, more so than in later stages. Also the grooving or simulation of coils on the exterior of bowls is comparable to a similar feature present on Pueblo I and II vessels in the uplands province.

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[40] Haury, 1932.

[41] Gladwin, 1935, p. 248.

Colonial: Red on buff and plain brown wares. The decorated vessels have a buff base color, generally enhanced by the use of a buff-colored slip, and designs drawn on with a red pigment. Vessels are bowls, jars, plates, effigies. Distinguishing features for the Colonial period are a typical bowl shape, like an inverted bell with a flaring rim, and the nature of the designs. Most of the decorations were formed by the repeated use of small elements bordered or fringed on one or both sides by sets of short, oblique, parallel lines. Common elements are figures resembling a simple or crude swastika, the letter z, the letter x, number 3; naturalistic symbols such as bird, mammal, reptile, and human forms; solid figures, triangles, rectangles, trapezoids, circles, the latter often enclosing a small element; interlocking scrolls applied in narrow bands. The kind of painted pottery which identifies the Colonial period has been named Santa Cruz red on buff. The brown vessels are called Gila plain ware.[42]

Sedentary: Painted pottery a clear buff base color with designs in red, a plain red ware with black interior, a terra-cotta red with black interior. The flared bowls survived into this period; there were also bowls of terra-cotta red with black interior. Painted vessels mainly jars and dippers. Jars large with sharply returned and flattened rims. The area of greatest diameter well below the center of the jar, producing a sharp angle, the Gila shoulder (pl. 9), and giving the effect of a flattened bottom, although actually rounded, vessel. Designs composed of panels, the chief elements of which are herringbone patterns, stepped lines, hachures, frets bordered with fringes of short, narrow lines. The negative type of design is common, and the patterns were tied together by interlocking scrolls. The name of the painted ware which identifies the period is Sacaton red on buff. The red with black interior is called Santan red ware, and the terra-cotta red with black interior is Gila red ware. The latter is believed to have developed in the eastern part of the province, possibly in the Mogollon district. Colonial sherds are also found at all Sedentary sites.[43]

Classic: Red on buff, terra-cotta red, and the introduced polychrome. The painted red on buff has a fainter base color than in preceding stages, often faded to a faint brown. New technique in the decoration of bowls. Interior colored a dull gray-blue by burning, and ornamented by a band of red decoration, usually a running fret. Outside decoration, bold designs, with cross-hatching common. Typical feature of the Classic is the jars (pl. 9). Body shape globular, but the Gila shoulder retained in modified form. Necks distinct from previous stages in that they were vertical. Negative patterns of frets commonly employed in decorations which closely resemble Sedentary designs. Vessel necks ornamented with square fret, panels of parallel or stepped lines, interlocking negative patterns. Main pottery of the period from the standpoint of the Hohokam seems to have been the terra-cotta or Gila red ware. Vessels in this group include square and rounded bowls, jars, pitchers, ladles, effigies, canteens, and eccentric forms. An occasional specimen is noted on which there is an exterior design in white, a thin zigzag line bordered by rows of dots. Apparently synchronous with the advent of the polychrome wares, there was a further development of the red on buff, in which bowls and small, wide-mouthed jars were smoke-blackened on the interior and given a high polish on the exterior.

In the polychrome group all visible surfaces have clear, well-polished red slip upon which bands and fields of white slip paint were applied as a background for the designs, which were either in black or black and red.[44] This is the ware which is correlated with the Pueblo peoples, and it was on pottery of this type

[42] Gladwin, 1933; Haury, 1932.
[43] Gladwin, 1933.
[44] Kidder, 1924, pp. 109–110.

that were based earlier conclusions that the Gila remains were a variation of the Pueblo. The typical red on buff jar forms which identify the period are called Casa Grande red on buff; the terra cotta red is Gila red ware.[45] The dull gray-blue bowls are known as "Tucson red on buff." [46] The polychrome group has a variety of names—Salado, Pinto, Tonto, Gila, depending upon the source and local characteristics.[47]

Recent: Large percentage of plain ware. It is generally red with heavy firing smudges. It resembles the plain ware of the modern Pima and Papago.[48]

Modern: The pottery is modern Pima, a highly polished red with designs in black, and the Papago, bright red bowls highly polished inside and out, and jars with a grayish or brownish buff base color and designs in a brownish red.

There are certain general features in the Hohokam which should be noted. The Pioneer stage was largely based on postulation until the winter and spring of 1934–35, when a site, Snaketown, near Phoenix, was found which gives definite evidence that there was such a period. The results of the work at Snaketown have not yet been published, so that it is impossible to give any of the significant details. Announcement has been made, however, of the finding of a form of Ball Court at that location. The Ball Court is a typical Mexican feature found in association with ruins throughout Mexico and for that reason suggests interesting possibilities for the origin of many Hohokam traits. Other Mexican features, for example, the backs from iron pyrite mirrors, also point significantly southward. What impressed the writer most in viewing the material from Snaketown was the closer similarity in ceramics between this stage and the Pueblo pottery than exists in the later Hohokam horizons. The reason for this is not apparent at the present time, but may be forthcoming when the material has been thoroughly studied and published reports are issued by Gila Pueblo.

Present indications are that Ball Courts are one of the traits that characterize the Colonial and Sedentary periods. Historic remains occur only in the south; in some districts other stages are missing. There was no Classic in the west where the Sedentary developed into the Modern. In the southern periphery, the Papagueria, there was no Sedentary. The great irrigation systems of the Gila and Salt River valleys attained their maximum development in the Classic. It is thought by the investigators in this province that the Hohokam cultural pattern flowed outward to affect peripheral areas where the people were in a less advanced stage of development, rather than that the Hohokam received its impetus from an exterior source. As stated previously, the Hohokam periods correlate roughly with the Pueblo stages. This has been indicated by

[45] Gladwin, 1933.
[46] Gladwin, undated, p. 119, type 2.
[47] Gladwin, 1930 b.
[48] Gladwin, 1930 a, p. 178, type 2.

the finding of Pueblo potsherds in Hohokam sites or an association of potsherds in border-line districts separating the two provinces. Pueblo I potsherds have been found in Colonial sites, Pueblo II–III in Sedentary, Pueblo III–IV in Classic. In southwestern New Mexico a series of sites designated Mogollon by Gladwin, which differ from both the Hohokam and the Pueblo, yielded a few northern sherds identified as Basket Maker III by the Gila Pueblo group but considered as typical Pueblo I by this writer, as well as some Colonial Hohokam. From this evidence it has been suggested that the Colonial existed through Basket Maker III, Pueblo I and II into early III. Since the site in question furnished a dendrochronological date of 900 and it is known that Pueblo I was in full flower in the north by 777, the cross finds are not as significant as they might be under other circumstances. Furthermore, no Hohokam sherds have thus far been found in any Basket Maker III sites. The Pueblo I material associated with Hohokam Colonial has been mainly of the Kayenta black on white type, which present evidence indicates to be later than the Chaco black on white or eastern form of Pueblo I. Under the circumstances it would seem precipitate to attempt any closer correlation than that of an approximate synchronization.

One of the interesting problems is that of the paddle-and-anvil pottery. The question naturally arises as to where this method was derived from and what relation it bears to the other areas where a similar technique was used. If the modern Pima are descendants of the Hohokam, their pottery-making methods may possibly be considered as a heritage from their predecessors. The Pima pottery is paddle-and-anvil finished, but it is built up by coiling, as is also the case in the southern California and Colorado River tribes. If the same was true for the Hohokam, there was not as great a difference in southwestern ceramics as the general statement, so frequently heard in discussions of late, of coiled versus paddle-and-anvil pottery would indicate. Basically they are similar, as Gifford pointed out a number of years ago when he stated "there are two methods of making coiled pottery * * * in the Southwest."[49] The distinction lies in the finishing processes.

COMMENTARY

The Pecos Classification has been enthusiastically praised on the one hand and ardently damned on the other. Its proponents have felt that it was the most outstanding advance in years, whereas those who have not subscribed to its tenets are convinced that it represents the ultimate in asininity. Both the pros and the cons, however, have shown a propensity to fall into the same error, namely, that of

[49] Gifford, 1928.

thinking that the classification was final. Such was not the idea of the conferences. The sequential systematization was intended to serve as a working hypothesis, to present in convenient form the data which were available at that time. Those taking part in its elaboration were cognizant of its dependence on evidence from one particular region, the San Juan, and realized that more information from other districts was needed. Consensus was that whenever clear-cut proof warranted a change, there should be no hesitancy about making modifications. An example of this willingness to change is shown in the case of the Hohokam.

Criticism has been forthcoming on several counts. In some cases the exceptions were well taken, in others they merely show a lack of understanding, a failure to read carefully or even attempt, it would seem, to discern the intentions of the classification. One frequently hears that there could not possibly be eight stages in the growth of the cultural pattern because there were not that many different peoples in the Southwest. Also, the twofold grouping of Basket Maker and Pueblo has been scored on the grounds that the actual skeletal differences do not mean anything because the two types are occasionally found together in recent sites. Some insist that even though the sequence has been established it is thoroughly unscientific and should be rejected. Such objections would not be surprising if they were advanced by laymen, but when they come from people who supposedly are thoughtful students of the subject they are a bit baffling. Among the more intelligent criticisms the outstanding are: That the use of a numerical system has too definitely fixed a time element for the whole province; that it implies a cultural homogeniety in all districts; that too great reliance is placed upon a single determinant, pottery; that there is no need for Basket Maker I when there is no evidence for it; that the various terms are not sufficiently defined; that the assumption that all elements in the complex, except agriculture and the idea of pottery making, were independent local inventions is open to question.

The Basket Maker-Pueblo remains are believed to be representative of a single cultural pattern. The various periods are not regarded as distinct cultures, but rather as stylistic or developmental sections of that pattern. It is not thought that the growth followed a smooth and orderly progression. On the contrary, it is believed that the advances were intermittent with periods of quiescence during which there was little change. It is the material from the intervals when conditions were static which furnishes the picture for each typical horizon. The lines of demarcation between stages are often vague, and there is an overlap of characteristics which may tend to be confusing, although these occurrences can generally be explained if all of the factors involved are carefully considered.

The progression of stages infers a certain degree of contemporaneity between sites of the same horizon, but it does not necessarily mean that they will fall within identical chronological dates. A specific stage in the development of the Pueblo pattern did not cut horizontally, from the standpoint of actual chronology, across the plateau. There may have been—no doubt, there frequently was—a difference in the precise years in which similar objects were in vogue in different districts. Also, it should not be expected that in every district each group passed through all of the stages. In some sections Pueblo I survived until it was supplanted by Pueblo III, the intervening II being omitted. Again, in other parts of the province Basket Maker III continued until it was replaced by Pueblo II. This explains statements in some recent publications that there is no Pueblo I and in others that there is no Pueblo II. Similar conditions were also pointed out for the Hohokam, where certain stages are missing in some sections.

There are numerous problems and many ramifications in the Southwest which cannot be included in the present article. Attention has been called to them by Kidder in the Pecos reports, by Kroeber,[50] by the Medallion papers, the bulletins of the Museum of Northern Arizona, and in this survey as originally published in the Anthropologist.

On the whole it may be said that archeological investigations in the Southwest have been producing good results. Despite the criticism directed toward them, both the Pecos and Globe classifications have functioned well when used with discretion and when allowances have been made for local variations. They have kept a broad view of the subject constantly before the investigator. Moreover, they have assisted students in other branches of anthropology and interested laymen in discerning what the archeologists are trying to do and what their progress has been.

In conclusion the writer may offer one suggestion with respect to what appears to be one of the "burning issues", the Pecos classification. Since the chronological implications of the sequence appear to be the cause of so much dissatisfaction and difficulty, a slight revision of the terminology may be proposed. Because the terms "early" and "late", as well as numerals, inherently indicate chronology, they may be omitted. With these factors in mind, the following nomenclature is offered for consideration.

Basket Maker: To designate the stage at present indicated by the titles Basket Maker II or Classic Basket Maker. This name was given as an optional term in the original Pecos list. Since there is no evidence for an antecedent stage, it is omitted.

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[50] Kroeber, 1928.

Modified Basket Maker: This would replace Basket Maker III, Late Basket Maker, or Post Basket Maker. The designation would have the merit of indicating that the level was basically Basket Maker, although somewhat changed in form.

Developmental Pueblo: This term used by Morris several years prior to the first Pecos Conference to supplant both Pueblo I and Pueblo II by incorporating them under the one heading. The complexities caused by the absence of one or the other in some sections and the difficulty of horizon determinations in others would thus be eliminated. It would indicate that the complex was in the evolutionary stages leading up to the maximum development.

Great Pueblo: An alternative title for Pueblo III in the original nomenclature, may be retained to designate the era which was truly the classic period of the Pueblos.

Regressive Pueblo: Replacing the Pueblo IV, this name would denote the period in which there was a general recession from the preceding cultural peak. Although in some respects the term might seem misleading because some districts did not attain their maximum development until this stage, it does, nevertheless, characterize the general trend.

Historic Pueblo: Another choice proffered by the original tabulation, instead of Pueblo V.

It is not thought that these names would solve the nomenclature problem in its entirety, but if they are employed to indicate the cultural level of each site, while the actual chronological position is determined by dendrochronology, much present confusion can be avoided. Also, certain psychological resistance to a more general acceptance of the classification might be lessened. It should be emphasized that these designations apply to the complex, house type, pottery, stone, and bone implements, etc., and not to a single element or series of years. The criteria outlined in the Basket Maker-Pueblo discussion would hold for this classification. Even in the case of the original Pecos nomenclature the several horizons should only be considered as indicating the cultural level, the chronology being established by tree-ring dates as suggested above.

Just after the completion of this article a paper proposing a method for the designation of cultures and their variations was published by the Gladwins.[51] It suggests a system of roots, stems, branches, and phases. Characteristic features of the phases are described in uniform terms which avoid such comparatives and prefixes as early, late, pre-, post-, etc. The Pecos and Globe nomenclatures for the main sequences as well as other familiar terms are retained. The authors state that the purpose of their plan is to furnish the

[51] Gladwin, 1934.

specialist with a means for making minor distinctions in the building up of sequences and at the same time supply those not concerned with the minutiae of classifications with broader terms. A series of charts illustrating the plan in use are presented. These include names of present linguistic groups and an attempt to fit them into the archeological pattern, which is a hazardous procedure in the present state of our knowledge but one which furnishes food for thought. The scheme has considerable merit in its wider aspects and is worthy of careful consideration. In some respects it offers solutions to classification problems discussed in preceding pages; in others it adds new ones. The writer does not agree with the interpretation placed on certain features in the Southwest nor some of the groupings in the charts, but that is a matter of viewpoint. The plan does provide a systematic method of classification and a means for presenting the archeological data in a diagrammatic way.

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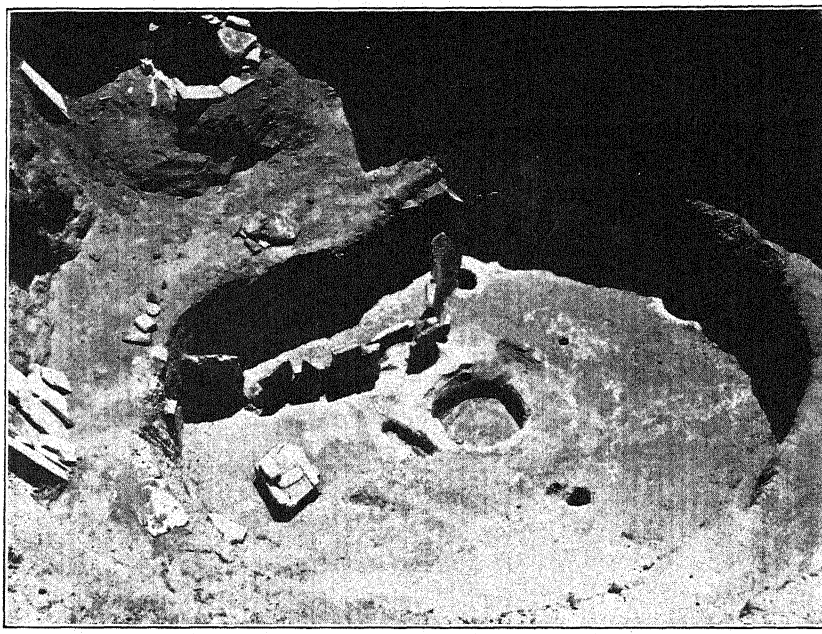
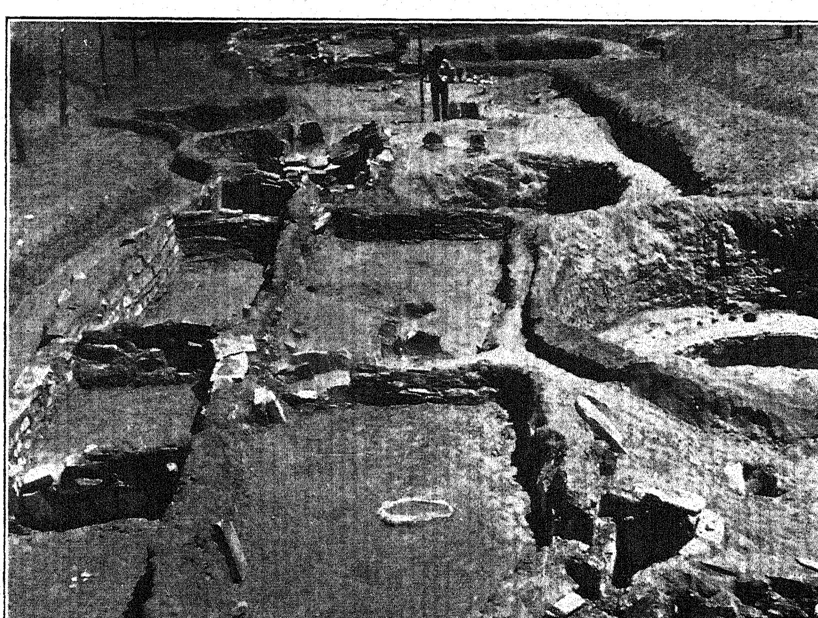
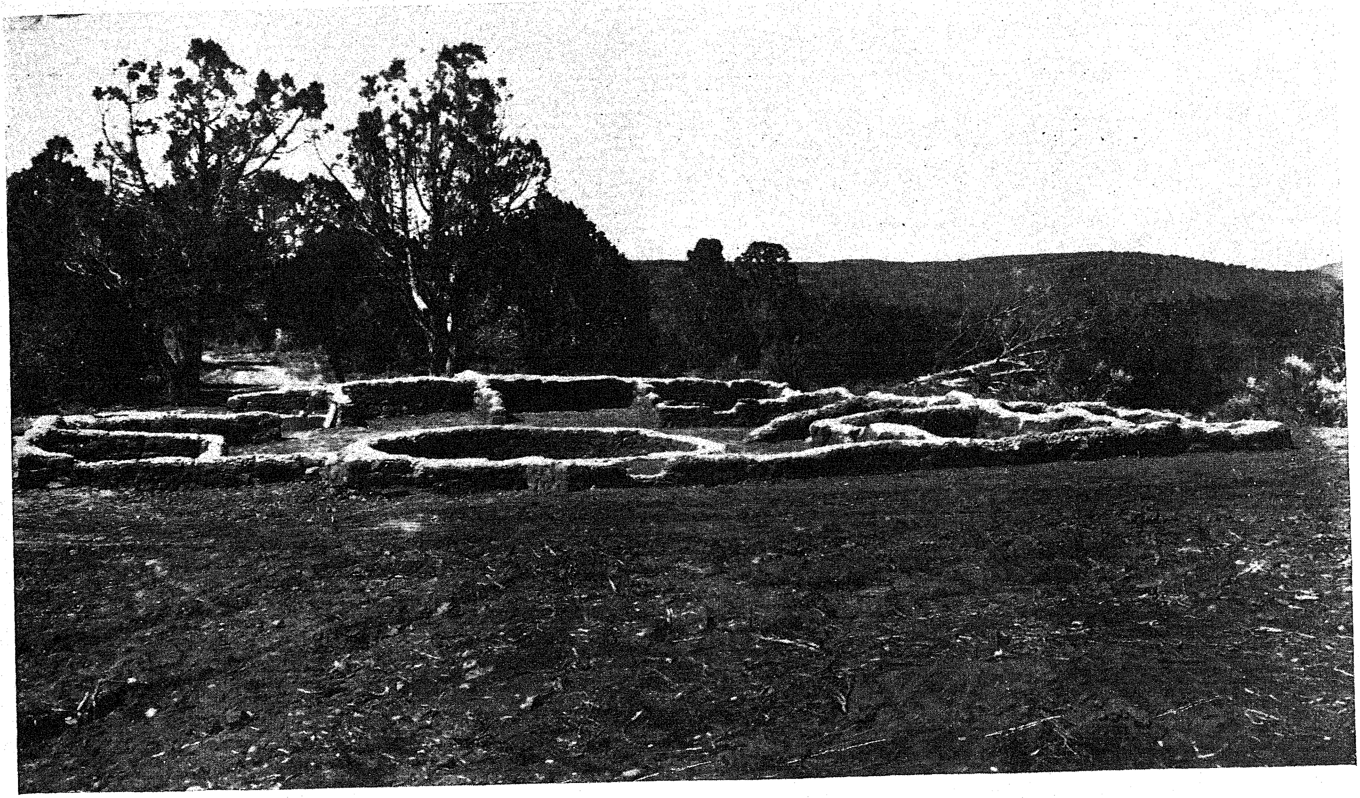


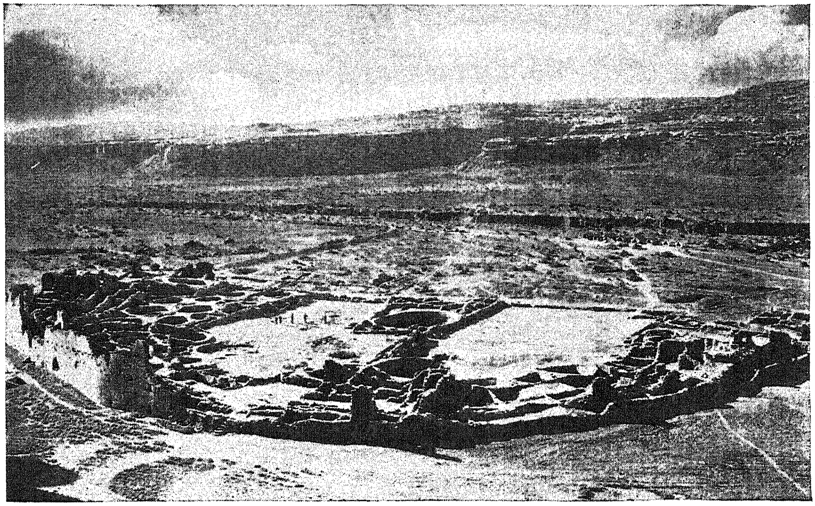
1. REMAINS OF TYPICAL PUEBLO I PIT HOUSE.



2. EXAMPLE OF LATE PUEBLO I UNIT WITH CONTIGUOUS ROOMS.

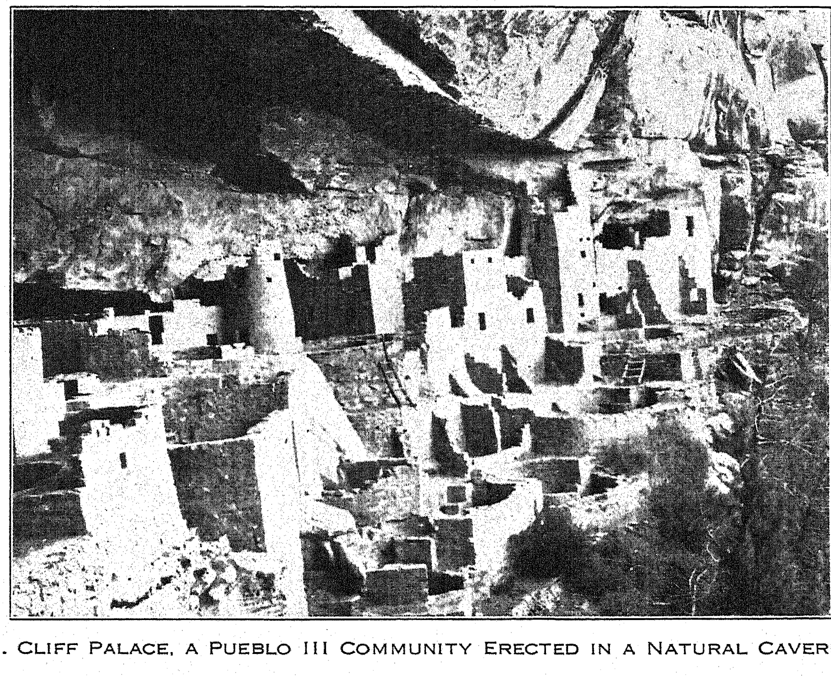


UNIT TYPE STRUCTURE, CHARACTERISTIC OF PUEBLO II.

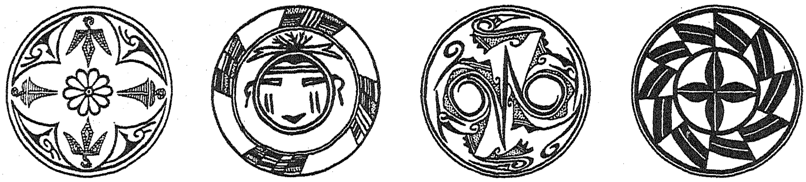


Courtesy National Geographic Society.

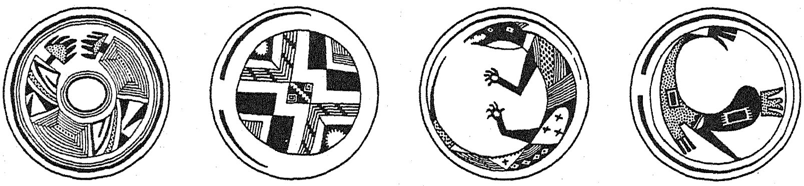
1. PUEBLO BONITO, EXAMPLE OF PUEBLO III STRUCTURE BUILT IN THE OPEN.



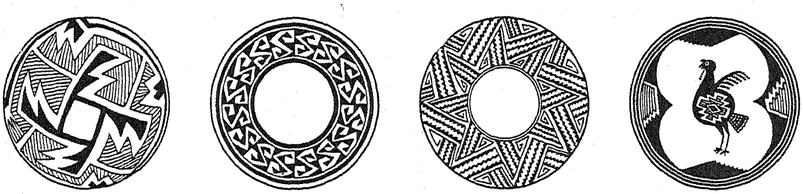
2. CLIFF PALACE, A PUEBLO III COMMUNITY ERECTED IN A NATURAL CAVERN.



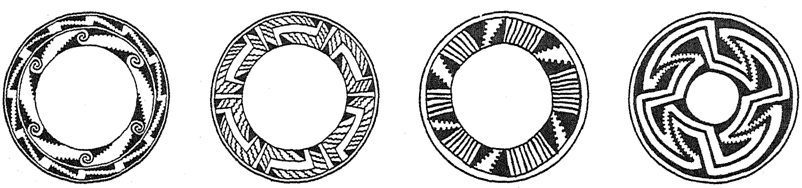
PUEBLO V



PUEBLO IV



PUEBLO III



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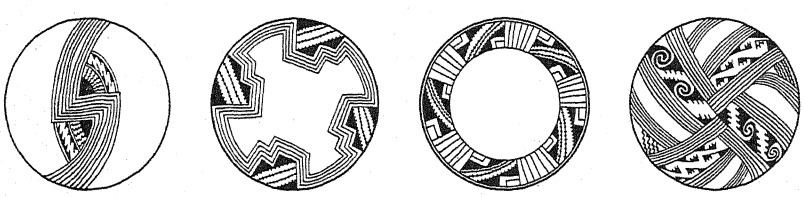
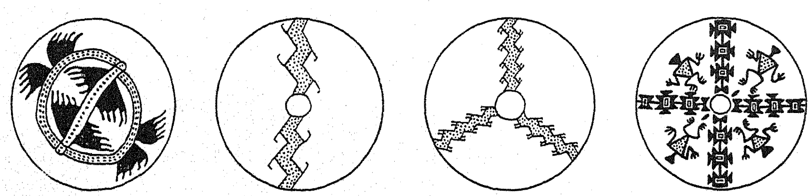
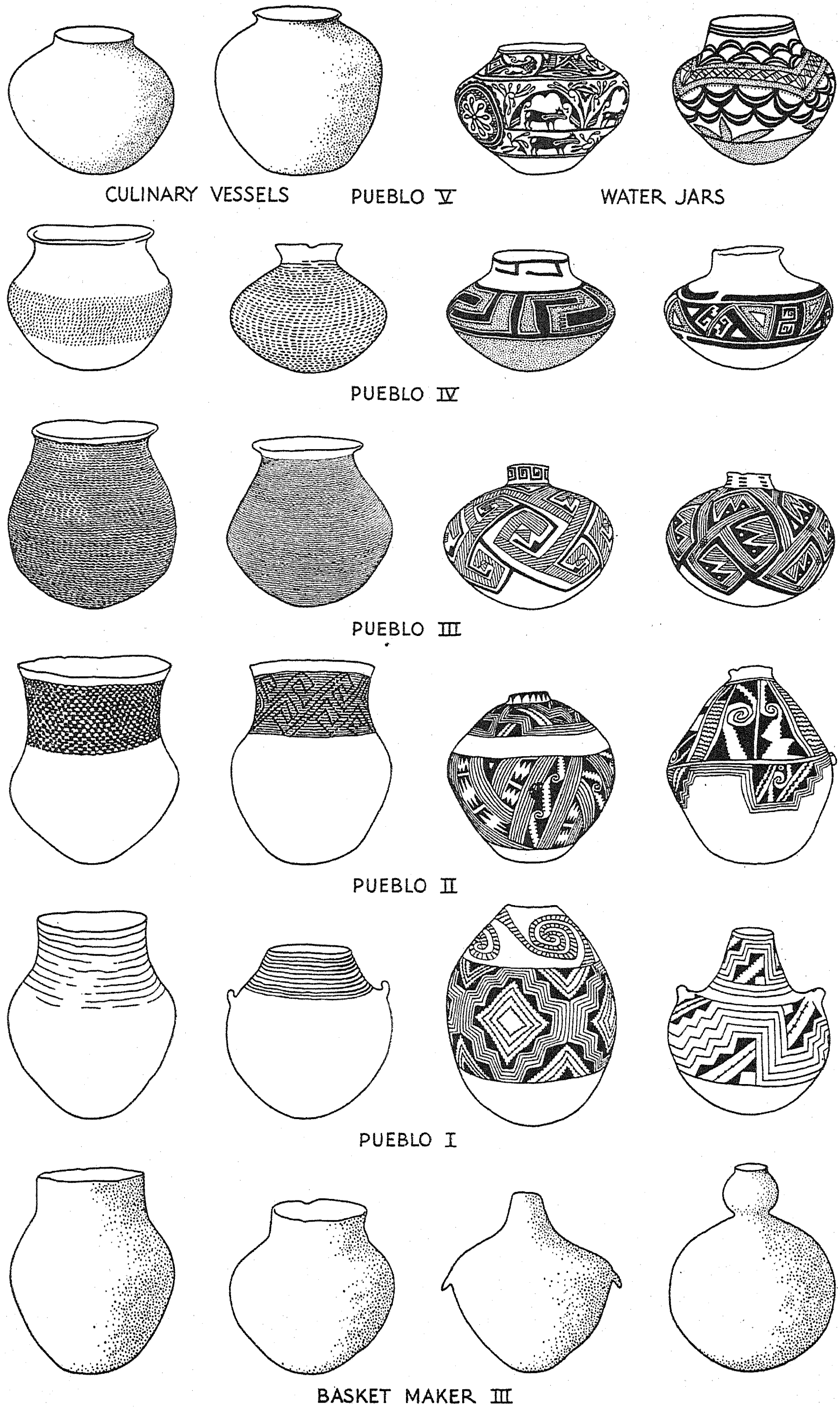


PUEBLO I

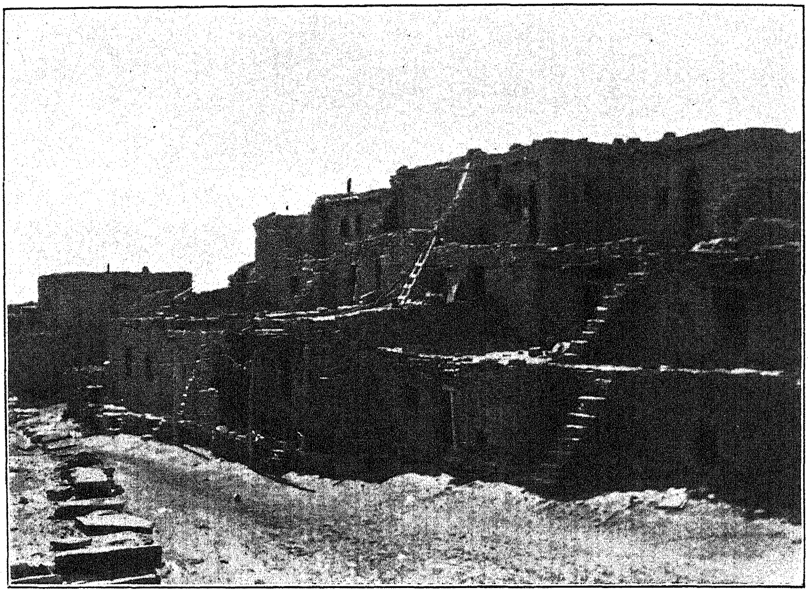


BASKET MAKER III

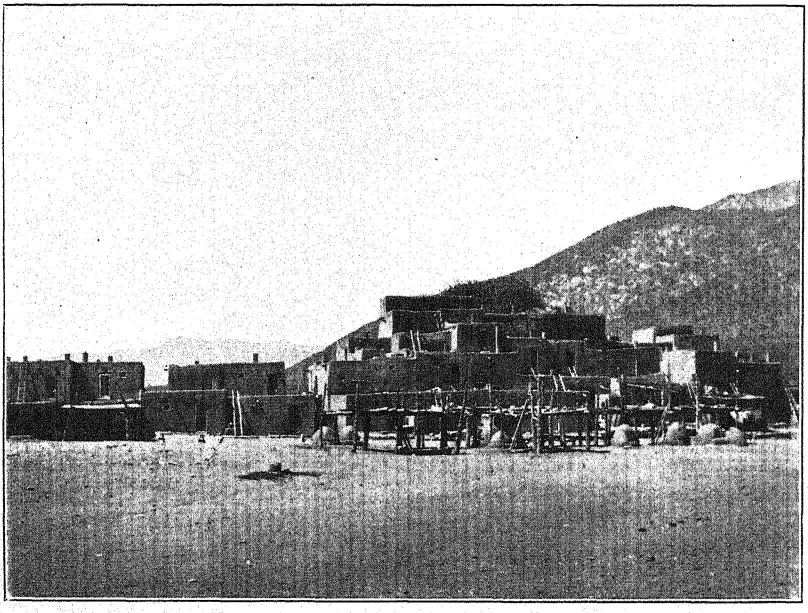
TYPICAL DECORATIONS FROM THE INTERIOR OF BOWLS, BASKET MAKER-PUEBLO PROVINCE.



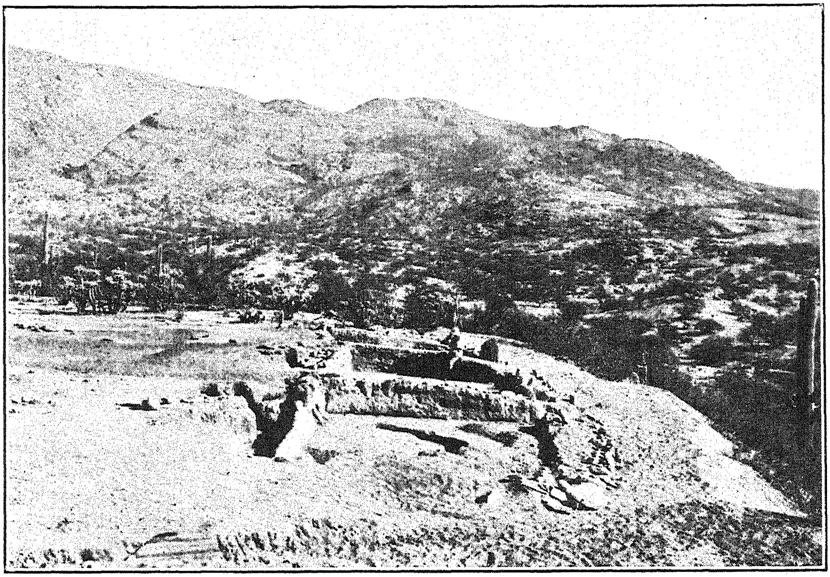
SOME CHARACTERISTIC VESSELS AND FORMS OF DESIGN IN THE BASKET MAKER-PUEBLO PATTERN.



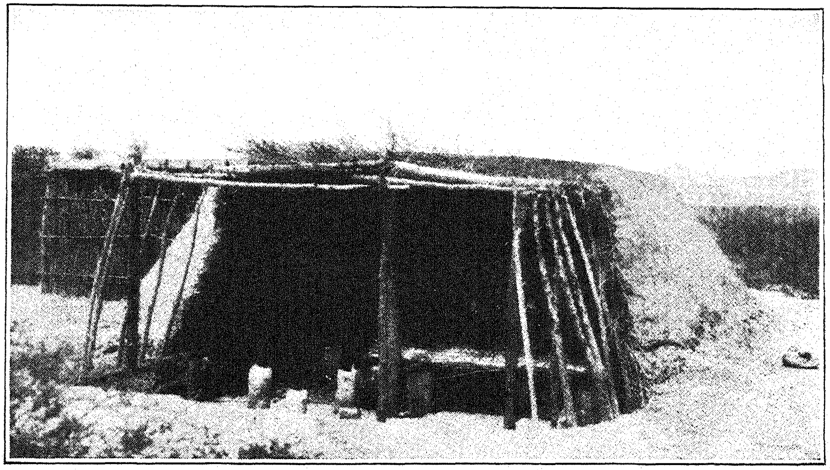
1. PORTION OF ORAIBI, A MODERN VILLAGE IN THE HOPI AREA.



2. BUILDINGS AT TAOS, PUEBLO V DWELLINGS



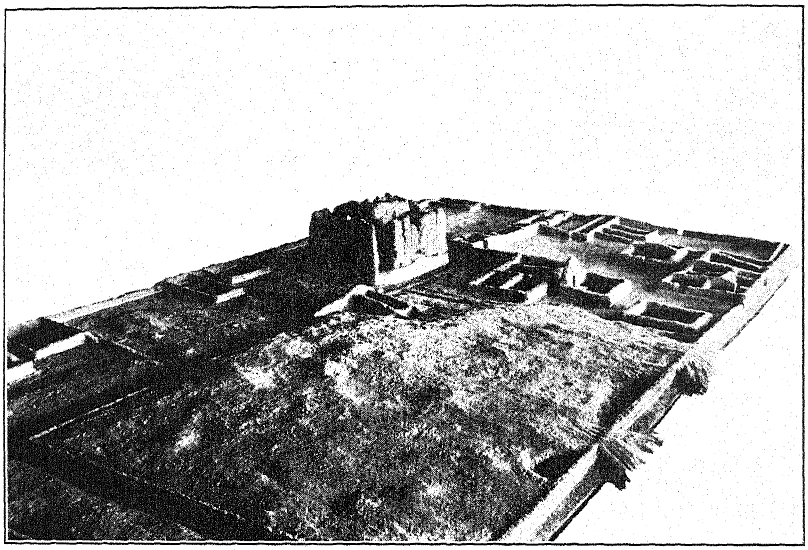
1. A COLONIAL HOHOKAM SITE IN SOUTHERN ARIZONA.



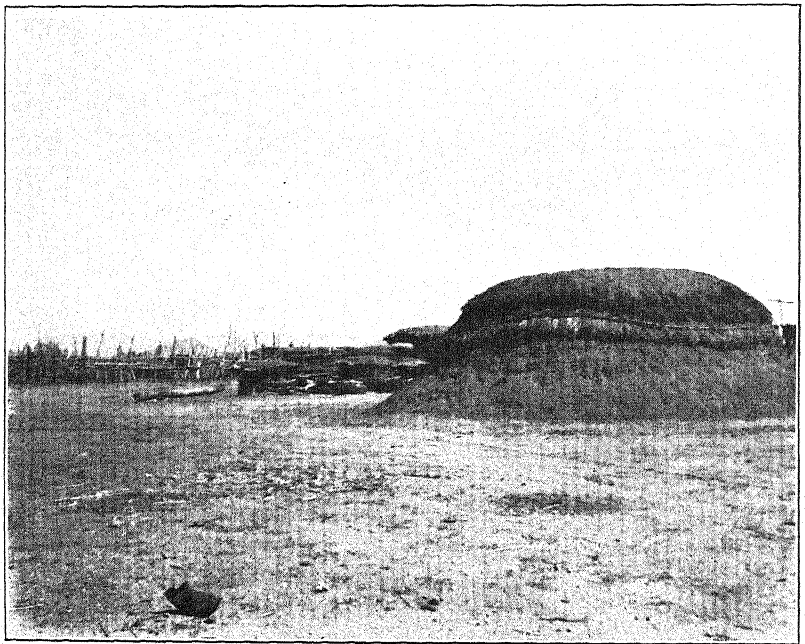
Medallion Picture.

2. RECONSTRUCTION OF COLONIAL HOUSE.

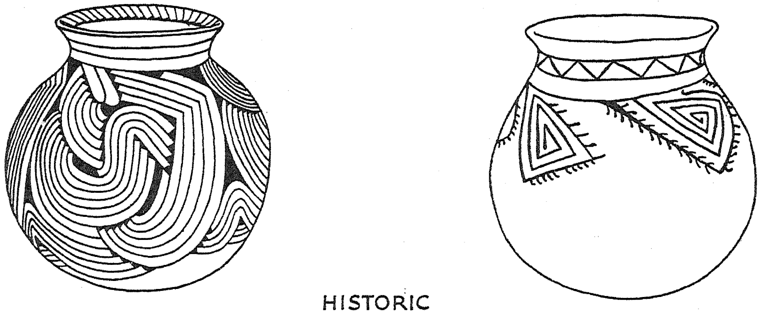
South end left open to show structural features. Entrance passage at left.



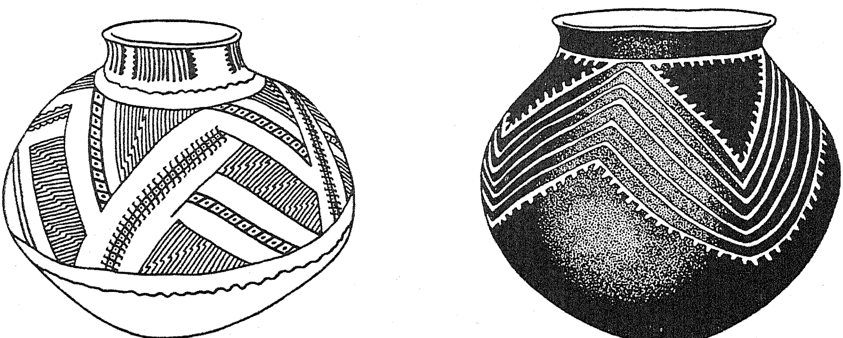
1. CASA GRANDE, CLASSIC HOHOKAM PERIOD.



2. MODERN PIMA VILLAGE.

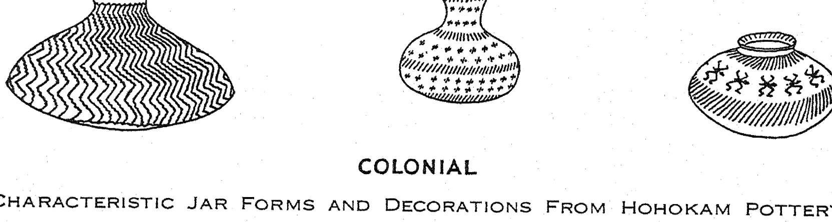


HISTORIC



CLASSIC

SEDENTARY



COLONIAL

CHARACTERISTIC JAR FORMS AND DECORATIONS FROM HOHOKAM POTTERY.

NUZI AND THE HURRIANS

THE EXCAVATIONS AT NUZI (KIRKUK, IRAQ) AND THEIR CONTRIBUTION TO OUR KNOWLEDGE OF THE HISTORY OF THE HURRIANS

By Robert H. Pfeiffer
Harvard University

[With 2 plates]

Before 1925 the very name of the Hurrian city of Nuzi was forgotten, and the information about the Hurrians was scanty and vague. In 1925 Miss Gertrude Bell, first director of antiquities of the Kingdom of Iraq, commissioned Prof. Edward Chiera, of the University of Pennsylvania, to undertake archeological excavations in northern Mesopotamia under the joint auspices of the Iraq Museum and the American Schools of Oriental Research. The chief objective of this work was to find the place of origin of certain cuneiform tablets with marked characteristics, such as non-Semitic personal names and outlandish spellings of Assyrian words, and to obtain such tablets by scientific excavations rather than by accidental finds or illicit diggings on the part of the natives. On the advice of Dr. Corner, the resident civil surgeon in Kirkuk, who had obtained such tablets from his native patients, Dr. Chiera chose for his excavations a small mound near the village of Tarkalan, about 10 miles southwest of Kirkuk, and thus he discovered the lost city of Nuzi.

THE EXCAVATIONS AT NUZI

In 1925–26 Dr. Chiera cleared the ruins of the house of Shurkitilla (about 1500 B. C.) and penetrated into some of the rooms of the adjoining house of Tehiptilla. In the latter he found the family archives, numbering more than 1,000 cuneiform tablets; 559 of these records have been published in five volumes by Dr. Chiera.

After an interruption of 1 year the excavations were resumed and were carried forward during four seasons (1927–31) under the joint auspices of the Fogg and Semitic Museums of Harvard University and the American Schools of Oriental Research.

In 1927–28 Dr. Chiera, assisted by Richard F. S. Starr, of Harvard University, and Emmanuel Wilensky, an architect, completed the work on the houses of Shurkitilla and of Tehiptilla, excavated another small mound covering the remains of two similar adjoining houses belonging to Zigi and Shilwateshub, respectively, and began the excavations of the largest mound in the vicinity, Yorghan Tepe, where he uncovered the central portion of the official residence of the governor of the city of Nuzi. Of the tablets belonging to the archives of Zigi and Shilwateshub, numbering more than a thousand, 265 have been edited in two volumes, prepared by Dr. Chiera and the present writer, respectively.

In 1928–29 the present writer, with the assistance of Mr. Starr, Mr. Wilensky, and Mr. P. Delougaz, continued the excavation of Yorghan Tepe, completing the work on about half of its surface. The great central palace and the two less pretentious residential areas adjoining it (see fig. 1), all dating from about 1500 B. C., were uncovered, and a test pit through the lower levels (in N120) yielded information about the occupation of the site during the third millennium B. C.

In 1929–30 Mr. Starr, assisted by Prof. H. F. Lutz, of the University of California, Charles Bache, of the University Museum in Philadelphia, Robert W. Erich, who made an anthropological study of the skeletal remains and the burials, and Mr. Wilensky, discovered the two temples situated on the northwestern half of Yorghan Tepe (see figs. 2 and 3), uncovered a portion of the city wall at the southwestern edge of the mound, and investigated Kudish Zaghir, a prehistoric mound in the vicinity.

In 1930–31 Mr. Starr, with Prof. Theophile J. Meek, of the University of Toronto, Mr. Bache, and Mr. Wilensky, completed the excavation of the upper levels of Yorghan Tepe and explored the lower levels in the temple area and in room L4 of the palace. In the latter pit he found more than 200 tablets dating from the third millennium, which proved that before the coming of the Hurrians, about 1900 B. C., the city standing on the site of Yorghan Tepe was called Ga-sur. These archaic tablets have been published by Dr. Meek.

THE STRATIFICATION OF THE MOUND OF NUZI

Yorghan Tepe rises on the average 5.5 meters above the present level of the plain. Virgin soil was reached only at three points: in room N120, at a depth of 5.4 meters below the level of the plain; in room L4, at a depth of 6.45 meters; and in a well in the court of the northern temple at a depth of 8.33 meters. The pit in room L4 was the most rewarding of the three. The 15 distinct levels of human

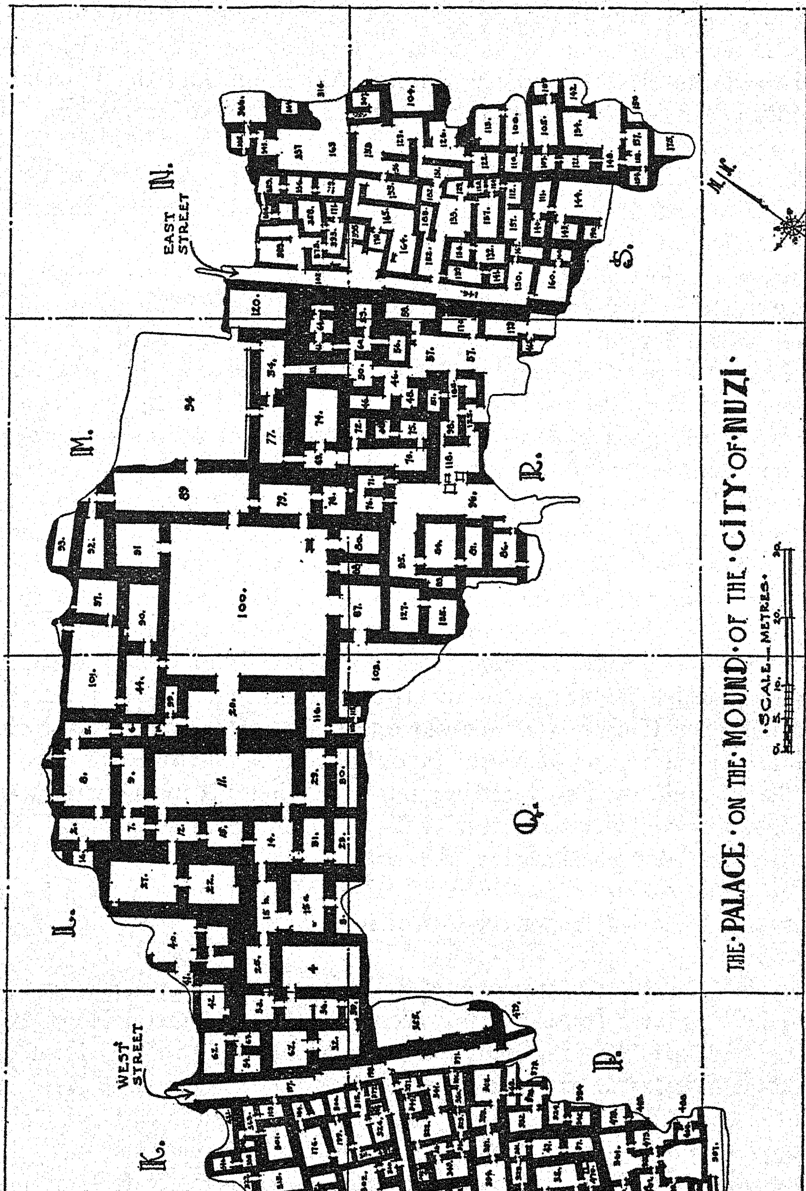


FIGURE 1.—The southeastern half of Nuzi: the government palace.

habitation that were revealed in this pit belong to three main cultures, viz, the second aeneolithic, marking the transition between the neolithic and the bronze ages, the Sumero-Akkadian, and the Hurrian. Twenty centuries elapsed from the date of the lowest level to that of the uppermost.

The Second Aeneolithic Culture (second half of the fourth millennium).—Levels 1–4, extending from 6.45 to 4.17 meters below the present level of the plain:

The archeological material from the first three levels, which is fairly uniform, consists chiefly of painted pottery of the "Susa II" type. Animal figurines in clay, whorls, needles, flints, and nobbed and incised ware were also in evidence. In the adobe walls individual unburnt bricks could not be distinguished. On level 4 signs of progress begin to appear. A rudimentary potter's wheel comes into use, and new types of pottery begin to displace the graceful painted specimens of the earlier levels. Well-made unburnt bricks can now be easily distinguished in the walls, and infant burials in bowls appear for the first time. These significant changes, which do not necessarily indicate the advent of alien invaders, were verified in the stratification of Kudish Zaghir, a small mound rising to 6.75 meters about 1½ miles south of Yorghan Tepe. The whole period of human occupation on Kudish is limited to the time of the four lowest levels at Yorghan, for Kudish was abandoned at the end of the prehistoric period. In the region of Mosul (about 100 miles northwest of Nuzi), Dr. E. A. Speiser discovered similar conditions: Tepe Gawra, like Kudish, is primarily prehistoric; Tell Billah (8 miles away), like Yorghan, is both prehistoric and Hurrian.

The Sumero-Akkadian Culture (third millennium).—Levels 5–13, extending from 4.17 meters below the level of the plain to 2.17 meters above it:

Levels 5–11 belong approximately to the first 6 centuries of the third millennium; the period between level 11 (0.69 meter below the plain) and level 12 (1.6 meters above the plain) as well as level 12 belong to the last 3 or 4 centuries of the third millennium; level 13 is dated by a tablet unmistakably Cappadocian about 2000 B. C. The culture of levels 5–11, although still presenting some relations with the earlier period in its early stages, is fundamentally that of the dynasty of Sargon of Akkad (about 2700–2500). This is particularly obvious in the case of the wheel-turned unpainted pottery, the cylinder seals and seal impressions (levels 8–10), and the cuneiform tablets (most of them on levels 9–10, a few on level 11; a single one, out of place, on level 7). Copper came to light on level 6, bronze on level 9. The ovens on level 5 are flat and without a vent hole, on level 7 high and with an aperture at the top, on level 8 they have the bee-hive

shape that became common in the later city of Nuzi. Certainly during the period represented by levels 8–10, and presumably for the whole period of levels 5–13, the name of the city was Ga-sur, and its population, as well as its culture, was predominantly Semitic Akkadian. Signs of a marked change begin after level 11 and continue through level 12: this period is a time of transition, with a mixture of old and new types of pottery and figurines. Level 13 marks clearly the end of the city of Ga-sur and the beginning of the city of Nuzi.

Hurrian Culture.—Levels 14 and 15: Though the Hurrians lived at Nuzi from about 1900 to about 1300 B. C., levels 14 and 15 in room L4 belong undoubtedly to the great palace of Nuzi and are therefore dated about 1550–1450 B. C.

The stratification of the other test pit, in room N120, confirms these conclusions, except for the absence in it of the aeneolithic levels (L4, levels 1–4). The four lowest levels of N120 (5.24 to 1.94 meters below the plain) correspond to levels 5–11 of L4 and belong to the city of Ga-sur. The present writer was amazed to find on the lowest level a complete skull, measuring 0.73 meter in length, of a large crocodile. The space between levels 5 (1.94 meters below the plain) and 6 (1.5 meters above the plain) corresponds to the transition period between levels 11 and 12 of L4. The topmost levels (7 and 8, 1.95 and 2.76 meters, respectively) correspond to levels 14 and 15 of L4.

After the Assyrians destroyed the city of Nuzi in the fourteenth century, the site of Yorghan Tepe was virtually abandoned and was used principally as a burial ground in Sassanian and Moslem times. There are, however, traces of sporadic and insignificant settlements. An Assyrian house could barely be identified from its indefinite remains. After the beginning of the Christian Era a few Parthian houses stood on the mound. Though some of these modest dwellings were built on the foundations of the ruined houses of Nuzi, they could be dated by the pottery with stamped decorations and by a few Parthian coins, drachms and tetradrachms of Volagases III (147–191 A. D.) One of these tetradrachms is dated in the month Dios of the year 153/4 A. D.

BURIALS

Two infant burials discovered in the L4 pit (below pavement 4) are indubitably *aeneolithic.* The body of one child was placed within a coverless jar and that of the other rested over a large potsherd over which a wall had been erected.

No infant burials of the *Ga-sur period* have been found. The graves of two adults seem to date from the very beginning of the Ga-sur period. Though no pottery was placed in the tombs, as in

the typically Ga-sur burials, other objects were found with one of the two bodies: A copper dagger, a cylinder seal fitted with a copper needle, and a copper leaf bent over at one end.

Thirteen graves of adults discovered in the L4 pit belong unquestionably to the Ga-sur period. Each one contained 1 to 5 jars or bowls and occasionally other objects. In one instance shells for cosmetics and beads were found; in another, in which the body had originally been wrapped in straw matting, two gold beads, a crescent-shaped gold earring, a copper pin with a glass knob, and a cylinder seal; in a third one, a copper chisel. Two other graves of the period were found in N120: One of the bodies was originally buried in a wooden coffin and had been provided with five vessels, an earring consisting of a silver loop supporting a crescent-shaped lapis-lazuli bead, and strings of beads used as bracelets and anklets; the other grave contained a large pot, two copper daggers, and earrings consisting of copper rings.

Extensive soundings within half a mile from Yorghan Tepe were made, but no cemetery of the city of *Nuzi* was discovered. Our information on the burial of adults in the Nuzi period is therefore distressingly meager. Only two burials in L4, utterly devoid of objects, belong to Nuzian times.

Nuzian infant burials, conversely, are abundantly exemplified. The remains of children not over 2 months of age were usually forced into U-shaped bowls made for funerary purposes only. These vessels were generally found in an inverted position or covered with smaller bowls. Although occasionally they were placed within walls, and in one instance inside a walled-up doorway, in most cases they were laid in rooms along the walls or, as at Ur in the Larsa period, just below the floor. In room S397 no less than 20 funerary bowls, each one of which held the bones of an infant, were found on the floor singly or in stacks of 2 or 3—all of them, except 2 that may have fallen from the stacks, in an inverted position. With these funerary bowls was also an urn, with a hole at the bottom and covered with an inverted bowl, containing the bones of several infants. Elsewhere a similar urn with a cover, containing the bones of at least 11 children, was found in the foundation of a wall; a third urn, with a large round opening at the bottom and a bowl covering the top, contained the bones of 5 children; it stood on the floor of a room. Three covered oval basins of unbaked clay, each containing a skeleton, were found in the foundations of walls or, in one instance, below a pavement. One of them had a few beads inside it and a vessel beside it—in fact, the only known example of Nuzian funerary donations.

The method in the disposal of the bodies of these infants cannot be inferred with absolute certainty from the finds. For though it is obvious that the bones, belonging in one instance to as many as 11 children, were dry and fleshless when placed inside the urns, the same cannot be asserted with equal assurance for the funerary bowls. It would have been possible to force a corpse immediately after death into one of the bowls and the actual condition of the finds is not inconsistent with this procedure, but it is rather difficult to conceive the presence of such bowls filled with decaying flesh on the floor of an inhabited house. The rooms containing funerary bowls belong to private dwellings, never to the palace or temples, and were not the rooms commonly lived in; they were, however, easily accessible. Nothing indicates that these rooms were domestic shrines. Few of the private dwellings had such mortuary chambers, and hardly any contained more than 1 burial jar; a few houses had 3, one 4, and one, S397, 20.

The natural assumption that these burials represent infant sacrifices, nay foundation sacrifices, cannot be demonstrated beyond doubt by means of the available evidence at Nuzi and elsewhere. In Palestine, for instance, the infant jar burials in the foundations of walls at Gezer and Megiddo may have been actual foundation sacrifices, but there is no literary evidence for this practice, for Joshua 6: 26 and I Kings 16: 34 are irrelevant in this connection. In any case, numerous other jar burials at Taanach, at Gezer, and at Carthage, like most of the Nuzi burials, bear no relation whatsoever to the foundations of walls. At Nuzi most of the funerary bowls were placed inside of inhabited houses; moreover, four Nuzi burial bowls came to light at Kudish Zaghir, where no houses had been erected for centuries. Though foundation sacrifices are unknown at Nuzi, it is not improbable that many of these children were sacrificed, but without the sanction of the official religion. If infant sacrifice were practiced, this barbarous rite probably originated in prehistoric times (for infant jar burials were found, as we have seen, in the aeneolithic levels), and savored of superstitious magic. It had either an apotropaic purpose (protection from evil influences) or, as the downward opening of the bowls and urns indicates, served as a propitiation to chthonian (i. e., subterranean) deities in the underworld. In any case the spirit of the deceased was to be barred from the land of the living.

THE TEMPLES

The excavations in the temple area have brought to light a series of seven sanctuaries, built or restored on the same site, during the period of a millennium (approximately 2500–1500 B. C.). The two

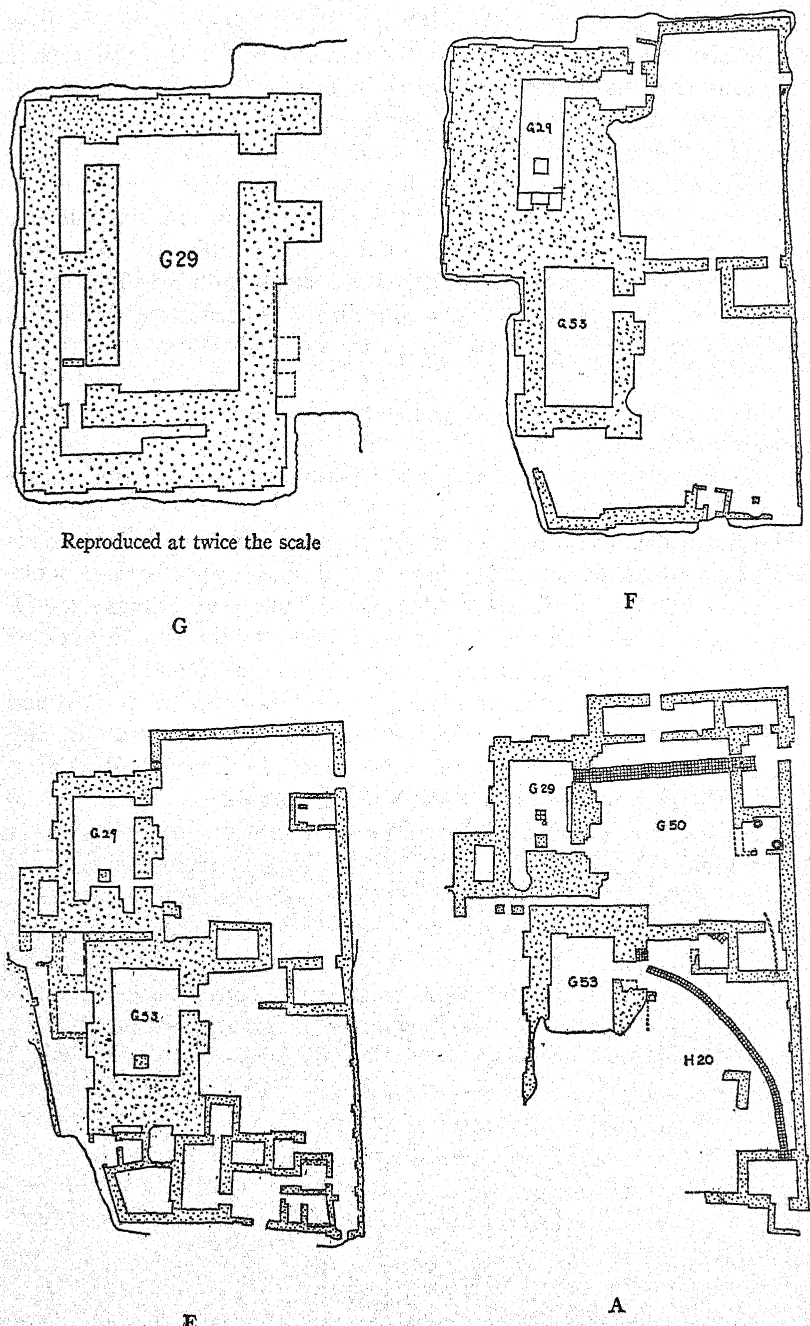


FIGURE 2.—The temples of Ga-sur (G, F) and of Nuzi (E, A) from 2500 to 1500 B. C.

lowest and earliest ones (indicated, for convenience, with the letters G and F) belong to the city of Ga-sur; the five later ones (indicated with the letters E, D, C, B, and A) to the city of Nuzi (see figs. 2 and 3). The building below Temple G, judged from its plan, was not a sanctuary.

Temple G exhibits the stately and unadorned massiveness and the simple symmetry characteristic of the ancient Babylonian shrines. The thick buttressed adobe walls of the rectangular structure may have supported turrets at three of the corners, though not at the corner by the entrance. The entrance door is preceded by a narthex (or outer porch) and gives immediate access to the adytum (or shrine) (G29). Within the adytum, in the wall facing the entrance,

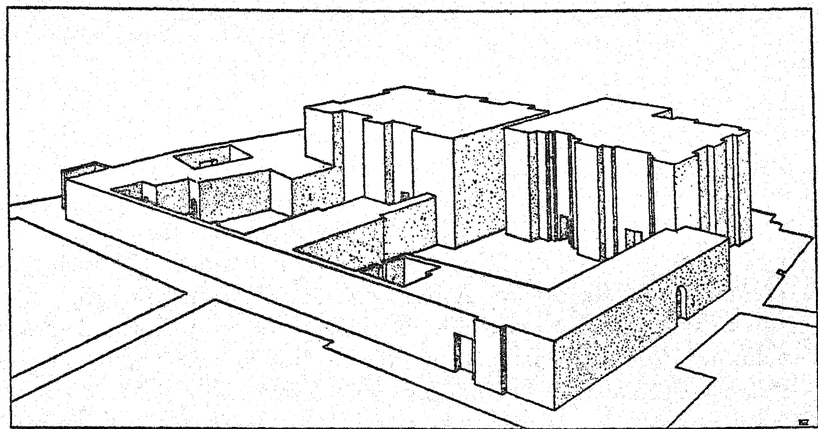


FIGURE 3.—Restored perspective view of the temple area, in its last stage, from the north.

2 doors admitted to 3 dark chambers tunneled inside of 2 walls; these narrow chambers could be locked and were conceivably used for storage. This temple, as the later ones, may have had a courtyard, but if so it has been totally obliterated.

Temple F is radically different from G. The adytum (G29), on the same level, was made considerably narrower by increasing the thickness of the walls. At the same time the chambers inside the walls were completely filled with carefully laid unburnt bricks, thus producing external walls of extraordinary width and solidity. The narthex was transformed into an enclosed vestibule provided with two external doors, one leading to the street, the other to the enclosed temple court. Of far greater importance than these changes is the erection of another complete temple along the southeastern wall. The new edifice was far less pretentious, but its adytum (G53) and the court (H20) were more spacious, its buttresses more conspicuous. Two chambers were built within the court; one was

accessible only from the court of the northern temple, the other served as a vestibule opening on the principal street. There was a gateway between the two courts in Temples F, E, D, but it was closed in Temples C, B, A.

The adytum of the older temple (G29) in this period (F) is at its best. A low altar of unburnt bricks (about 1 meter to the side and 0.33 meter high), with a concave top still retaining traces of fire, stood before the end wall, presumably in front of the image of the deity (Ishtar?). A raised brick at one of the corners of the altar served perhaps as the pedestal for the clay model of a 3-story house found in fragments nearby. A pilaster (1.26 meters wide and 0.56 meter deep) occupied the center of the end wall and had a step (0.15 meter high) before it and two platforms (0.32 meter high) at its sides. The lower part of the walls was wainscoted, and their upper part was painted red.

The work of restoration that produced the *E Temples*, undertaken presumably by the newly arrived Hurrians, was confined at first to the southern temple. In the adytum (G53) a square column of mud brick, apparently used as a pedestal, stood about 1 meter from the end wall, slightly off center. Along the lateral walls stood benches of unburnt brick (0.37 meter high and wide), not unlike those that in the early Ishtar temple of Ashur supported divine images. The adytum was divided into two chambers but only for a time. A group of rooms of inferior construction surrounding a courtyard occupied about half of the area of the temple court (H20).

When the northern temple was restored after a period of complete neglect, the two temples were almost separated by means of a narrow blind alley, but this passage was blocked again to strengthen the walls. The rebuilders of the northern temple preferred to follow the lines of the wider adytum of G rather than those of F and imitated some of the features of the adytum of the southern temple (G53). The walls were narrowed and had more pronounced but less graceful buttresses than in F; an isolated pedestal stood near the end wall, and benches were built along the walls right and left of the main entrance. Another door was opened into the adytum from the court, and a dark chamber was added. In the courtyard (G50) the vestibule leading into the adytum was removed, but two small rooms, one of which sheltered a well, were built along the walls. Subsequently, perhaps in the period of temple D, 2 niches were dug in the end wall of the adytum at the 2 sides of the pedestal.

Temple D, in a general way, represents merely a superficial restoration, with occasional wall painting, of temple E. The level of the southern temple (G53) was 0.3 meter higher than that of E, whereas that of the northern temple (G29), rebuilt more recently, remained

unchanged. In G29 a square hearth, consisting of four bricks flush with the pavement, was used as an altar. Near it was a bowl embedded in the floor, serving an unknown purpose.

In *Temple C* the two edifices were separated by a passage giving access to the northern court (G50), and the gateway between the two courts was permanently walled up. In the adytum of G29 the bench on the northwestern wall was removed. Four rooms were built in the court (G50), and rounded buttresses were added to its northeastern wall. The well and the room housing it were abandoned, but an oven, a storage pit for cereals, and a cooking stand were now provided for the temple attendants. In the southern temple (G53) the rooms located in the court (H20) were rebuilt on a new plan. Some of these rooms were eliminated in *Temple B*, which presents no other notable changes.

Temple A was never rebuilt after being looted by the Assyrians. The passage separating the two shrines was narrowed, some of the rooms in the two courts were rebuilt with changes, and processional brick sidewalks, leading from the main street entrance to the principal door of the shrine, were laid in each court. In the northwestern wall, as in temple F, a new entrance was opened into the court of the northern temple (G50).

The cupidity and vandalism of the looters wrought havoc with the decorations and statuary in the adytum of the northern temple (G29). The statue of Ishtar that presumably stood on the pedestal in G29, judged from a few small fragments that have been recovered, was slightly smaller than life size and was modeled in clay, partly glazed green, and partly covered with a thin sheathing of gold. Two pairs of fine clay lions, one pair couchant, painted red with spots of yellow glazing (pl. 1, fig. 1), the other pair standing, glazed green; a sheep's head and a boar's head glazed green; bizarre angry lions couchant and grotesquely fat standing ones used as jars, all in plain clay; Ishtar figurines and amulets; and thousands of beads hanging originally in festoons along the walls or set in the mud bricks, adorned the adytum. Most of these objects, however, were thrown into the court by the looters. Many of these ornaments, found on the floors of Temple A, belonged originally to earlier temples.

The southern temple, probably dedicated to Teshub, the weather god of the Hittites and Hurrians, was far less ornate; no glazed ware and statuary, comparable to that of the older temple, came to light in the adytum or in the court of the southern temple.

THE CULTURE OF GA-SUR

Temples G and F, already described, are the only buildings of the city of Ga-sur (third millennium B. C.) that were completely exca-

vated; Ga-sur levels were reached elsewhere only in the test pits that were sunk in rooms L4 and N120.

Through the conquests of Sargon of Akkad (Agade) and of his great dynasty (about 2700–2500 B. C.), the first Semitic empire in history was established and the Akkadian culture, which was much indebted to the earlier Sumerian culture, was carried to northern Mesopotamia and even into Asia Minor. Ga-sur was one of the Akkadian colonies established to develop commercial intercourse between the distant regions of the empire, and it is of particular importance to us because it is the only one, outside of southern Babylonia, of which we have commercial records. These cuneiform tablets of Ga-sur consist of letters, receipts, contracts, land records, and the like. They bear witness to business relations over a wide territory, extending from Ashur in the west to Simurrum and Hamazi in the east, and reaching as far south as Akkad. The relations with ancient Ashur, which at the time was likewise largely inhabited by Akkadians (though both Ashur and Ga-sur may have been originally Sumerian), were particularly close—if not always friendly. In one of the early inscriptions from Ashur a certain Ititi relates the dedication of a certain object "from the booty of *Ga-sag*" (a variant spelling of *Ga-sur*) to the goddess Ishtar. This name Ititi is of frequent occurrence at Ga-sur, where many of the 500 personal names known contain a similar repetition of a syllable (e. g., Ababa, Bazaza, Bazizi, Bubu, Dada, Dudu, etc.; the latter three are also divine names). Such iterative names were common in Babylonia during this period, but they tend to disappear there about 2300 B. C. Their popularity persisted, however, in Elam and Cappadocia—an indication of the non-Semitic origin of this vogue. At Ga-sur, however, most of the personal names, including the iterative ones, are Semitic.

The earliest geographical map known to us was found among these clay tablets. It shows two rivers, joined at the southeastern corner of the map—the *Rakhium*, which empties itself through three channels into a northern sea, and the . . .*-ru-um*, which flows westward; also two chains of mountains and three or four cities, one of which is called Mashkan-dur-Ibla, "the site of the fortress Ibla." The identification of the region represented by the map rests on the interpretation of the words "*sha-ad/t a-za-la*" written in its center. If we translate "Mount Azala", the region is somewhere in northern Syria between the Anti-Lebanon and the Zagros range, where there is a city named Ibla; if, however, we translate "field of Azala" or "belonging to Azala", the map represents a landed property, comprising "354 *iku* of cultivated land", belonging to a certain Azala.

The pottery ware of Ga-sur is of three types, domestic, sepulchral, and sacred. The first type exhibits such practical devices as handles, spouts, and holes for the insertion of rope holders, as well as decorations and burnishings, that are totally lacking in the more archaic and severe vessels buried with the dead. The temple vessels are more consciously artistic both in ornament and shape. The decoration is rarely in relief but consists usually of designs, made with incised lines, and of stippling. The most characteristic in shape among the vessels for ritual use are the theriomorph (or animal-shaped) containers, representing birds, and jars with spouts in the shape of a ram's head or having a snake in relief on the outer surface. One of the large storage jars has a border showing a wolf, in relief, attacking nine heads of cattle guarded by a man and a dog, all of which are outlined with incised lines.

Comparatively few clay figurines were found on the Ga-sur levels. One represents, in low relief, a god and a goddess seated side by side. Animal figurines are rare, whereas models of beds and of chariots are common. Reliefs of female figures in white marble are more common than clay ones, whereas the opposite is true in the Nuzi period. Three cylinder-seal impressions on clay are known: one has a geometric design, another represents the familiar scene of a worshipper led to a deity, and the third one represents a pair of intertwined standing bearded bulls and a pair of intertwined standing lions. This last impression is on a bulla, which, according to the inscription, sealed a receptacle containing a "balance of sesame." Among metal objects, copper ones are the most varied: a small standing figure, sun disks, crescents, pins, bracelets, a small football-shaped bell, daggers, and sickles. One of the sickles has the puzzling inscription "*an ud za*"—possibly the name of a deity otherwise unknown.

The culture of Ga-sur is fundamentally Akkadian. However, a well-written Sumerian catalog of occupations and professions and the common use of Sumerian ideograms in the tablets indicate a decided Sumerian influence at Ga-sur. The culture of Ga-sur presents striking similarities with that of Ashur. Near the end of the third millennium Ga-sur had close commercial relations with the trading posts that Ashur had established in Cappadocia, as shown conclusively by the Cappadocian letters found at Ga-sur; the unexpected discovery of typically Hittite double axes at Ga-sur corroborates this evidence of the relations of Ga-sur with Asia Minor.

THE BUILDINGS OF NUZI

Nuzi proper is really an acropolis rather than a city. There is no reason to assume that Nuzi extended appreciably beyond the edges of Yorghan Tepe, a square mound measuring 200 meters on a side, with

its corners oriented toward the points of the compass. The exact limits of the town are, of course, unknown, for erosion has completely obliterated the city wall except at one point on the southwestern side. This wall belonged to the late Ga-sur period, but the gateway connected with it seems to have continued in use in the Nuzian period. Within the walls, on the upper levels of Yorghan Tepe, were the temples already described, the government palace, offices, and tenement houses. Outside the walls, arranged in two groups north and northeast of the town, were the suburban homes of the more affluent Nuzians. Two of these suburban houses have been excavated, the double house of Tehiptilla and Shurkitilla, and the double house of Zigi and Shilwateshub.

The town of Nuzi was presumably enclosed within four walls measuring about 200 meters on a side. The main street, connecting the two city gates at the center of northeastern and southwestern walls, divided the city into two quarters, the temple area in the northwestern section and the palace compound in the southeastern. This street, which was the only paved street of the town as well as the widest and best drained, was the principal traffic artery of the congested town.

The temple area.—The temples were built along the principal street and were surrounded on the three other sides by closely constructed apartment houses, which were generally more spacious than the similar dwellings adjoining the palace. The building at the northern corner of the city seems not to have been used for residential purposes during the last years of Nuzi, and it is the only one that was rebuilt on the same plan when the city was destroyed. Its proximity to the temples, the presence of pavements of unburnt brick laid over a porous substratum, and its generally careful construction indicate that it was a public building, possibly the business office of the temples or the treasury of the town.

The palace area (fig 1).—Like the temples, the great palace of Nuzi adjoined the main thoroughfare and was flanked on the northeast and on the southwest by residential areas. On the southeastern side erosion has totally obliterated the buildings that presumably stood there. Two narrow lanes, beginning probably at the main street, separated the palace from the residential compounds and gave access, through doors and alleys, to the several apartments of the two residential districts.

The *southwestern* district was better planned than the northeastern. Only 3 of the 13 separate apartments in this area, however, had a drainage system, and none had a well.

The *northeastern* district was less extensive and less intact than the other. Of the 8 separate dwellings of the district, 3 had paved courtyards. Within some apartments certain groups of rooms were

segregated and independent. The rooms closest to the palace, which are generally smaller, may have housed servants of the governor. One of the house units actually utilizes the palace wall.

The great *palace* of Nuzi, by far the most important and best built edifice of the city, was the government building and the official residence of the governor of Nuzi. Through an admirable general plan, more than 100 large and small rooms were organically related within a single architectural structure. The massive walls, the brick pavements of courtyards accurately laid over a stratum of sand, the efficient drainage system, and the abundant sanitary facilities cannot be matched in the other buildings of Nuzi. At "the gate of the palace", according to the records, many of the tablets were written, but this gate has been totally obliterated by erosion. The location of this gate can be fixed, with reasonable assurance, at the northern corner of the building on the main street near the northeastern city gate. Through this entrance one entered a spacious courtyard (M94) provided with seats along the walls, ostensibly for the convenience of those seeking audience with the governor or transacting business at the gate, according to the well-known practice of the Israelites. A door in the southwestern wall of M94 led to three rooms of decreasing size (M 89, 79, 78), two of which gave access to the great central courtyard of the palace (M100). Two doors in the southeastern wall of M94 led to a subordinate eastern wing of the palace having no direct access to the central courtyard. This wing probably housed minor officials; its southwestern portion consisted of a kitchen and bakery built around a courtyard with a square well; its northeastern section comprised business offices, a courtyard with a round well, restricted sleeping quarters, and water closets.

The main central courtyard (M100) was originally paved in baked bricks; the bricks of its central portion were removed while still exposed after the destruction of the building. Brick facings still remain along its four walls and within its eight doorways. Subterranean terra-cotta pipes drained the rainwater from the roofs. After passing under the kitchen and the water closets of the service quarters at the eastern corner of the palace, the water carried the refuse through a brick *cloaca maxima* to a considerable distance in a southeasterly direction. The three doors in the southeastern wall of the courtyard led to a group of rooms, partially obliterated, adjoining the service quarters. The two doors in the northeastern wall were the entrances from the street (through M94 and two vestibules). One of the two doors in the northwestern wall led to a group of rooms built around a paved courtyard (L101); one of them was a storage cellar containing 37 large jars and smaller vessels.

The great doorway through the southwestern wall, the most important of the eight in the courtyard, had twin wooden doors and

a porch supported by pillars standing originally on two extant platforms. This door led into a large anteroom (L20) giving access to the largest and most imposing room of the palace, L11, located at the center of a group of unusually small rooms—the reception hall of the governor. The doorway from the anteroom had a massive wooden door studded with copper nails, some of which were covered with thin silver sheathing. The lower part of the walls of the audience hall was painted in bright red, as also a dais, 0.22 meter high, along the northwestern wall; the upper portion of the walls was probably decorated with elaborated painted friezes, if we may judge from the remarkable fresco (pl. 1, fig. 2) adorning a dark corridor (L15b) leading to the most richly appointed water closet of the palace (L25). The design of two upper bands of this painted frieze, divided off vertically by the typically Nuzian twisted rope motif, is geometrical; the lowest one consists of a series of panels representing the conventionalized sacred tree, an ox head, and a broad female face with cow's ears and Egyptian coiffure. The style of this fresco is vaguely Minoan. In other rooms surrounding the reception hall the lower part of the walls still retains traces of broad painted black-and-gray stripes. All these rooms connected with the audience hall were obviously the living quarters of the governor of Nuzi, but their specific use is not easily determined, except in the case of storage rooms and of the single water closet (L25) in this part of the palace. It is possible, however, that one of the rooms northwest of the hall was the private chapel of the ruler of the city.

THE WRITTEN RECORDS OF NUZI

The clay cuneiform tablets of Nuzi, dating from about 1550 to 1350 B. C., number more than 4,000. A few were found accidentally by natives and have been known for years, but the bulk of them were unearthed in the excavations of 1925–31, about half at Yorghan Tepe and half on the suburban Nuzian homes. Practically no tablets of the Nuzi period from Yorghan Tepe have been included among those, numbering nearly 1,000, that have been published. This cursory survey, however, will not be confined to the published material.

The archives from the houses of Tehiptilla and of Shurkitilla disclose the commercial and domestic activities of the descendants of Puhishenni through four generations, but primarily those of his son Tehiptilla, whose name appears in at least half of these records. Judged from the 559 tablets published by Professor Chiera, most of these texts are conveyances of real estate (in the form of contracts of adoption, affidavits, and court decisions) by the indirect method of adoption and bequest. Exchanges of fields, mortgages, loans, and

receipts are also abundantly represented in these archives. The house of Tehiptilla prevailed in court over its opponents in all the 53 lawsuits on record. Far less numerous are the documents of the following types: Adoptions of free women for marriage to household slaves; marriages, wills, stipulations of voluntary slavery on the part of "Hebrews" (*Ḫabiru*), agreements, gifts, sales of horses, bills of lading, contracts for the hire of harvesters, letters, lists, inventories, and so on.

All these types of documents appear, in varying proportions, in other family archives. The house of Zigi was less concerned in the acquisition of landed property, through inheritance from the fictitiously adoptive fathers, than the house of Tehiptilla; its preserved records deal primarily with family matters, such as marriages, wills, genuine adoptions, with litigation in court concerning such matters, and with mortgages. Shilwateshub, son of the King, according to his tablets, increased his wealth by making loans of cereals, payable with the interest after the harvest, and by sheep raising. A lady named "Tulpunnaya", whose records were found in room N120 of the palace, adopted young women for marriage to her servants or, against the payment of the bridal price, to Nuzian bachelors. She claimed the offspring of the wives of her slaves as her property and she also added to her household servants by seizing the persons of her debtors or of their sons pending the complete repayment of the loan. Puhishenni, the son of Mushapu, who lived in the district northeast of the palace, acquired fields through adoption, raised sheep, and loaned sheep and cereals at interest. He once provided an illiterate shepherd with a hollow, egg-shaped tablet containing 49 pebbles corresponding to the 49 sheep entrusted to his care, according to the inscription on this tablet and on the duplicate record retained by Puhishenni.

Aside from private records, such as those of Tulpunnaya and Puhishenni, the tablets from the palace of Nuzi include official documents, such as lists of tax collections and of payments of wages to female weavers and other workers, records of payments (from the state treasury?) for the support of the "queen" of Nuzi and the "queen" of the City of the Gods, reports on military inspections, religious and scholastic texts, and court records. Among the last is the transcript of the testimony presented in a suit for the impeachment of a governor accused of soliciting bribes.

THE HURRIANS AND THEIR CULTURE

Hurrian personal names occur sporadically in the third millennium B. C. in Babylonia and in Cappadocia, but the great Hurrian migration is not earlier than the beginning of the second millennium.

Soon after 1900 B. C. we find the Hurrians in undisputed occupation of the conquered cities of Nuzi and Tell Billah (just north of Mosul). Not long after, their presence is attested in Palestine and in Syria. The Old Testament calls them Horites, and the Egyptian name for Palestine beginning with the New Kingdom is Haru or Huru. Hurrian names occur in the cuneiform tablets of Taanach. The Tell el-Amarna records and the Hittite archives vouch for their presence at Aleppo and elsewhere. At Ras Shamra, near Latakiyeh, Hurrian texts in a new cuneiform alphabet have recently come to light.

The connection between the spread of the Hurrians and the other great ethnic movements in the first half of the second millennium, namely, the Hyksos invasion of Egypt, the Cassite conquest of Babylonia, and the appearance of the Indo-Iranians in Anatolia, is still obscure, because we have no information concerning the place of origin and racial stock of the Hurrians. Their very name is in dispute and appears variously, in recent publications, as Harri, Mitannians, and Subareans.

The kingdom of Mitanni, on the upper Euphrates, is the only Hurrian state that played an important role in international affairs. Its population and its language were primarily Hurrian, but the kingdom was organized and dominated by an Indo-Iranian aristocratic minority that exhibited a genius for government and, incidentally, a love for the horse that are typically Indo-European. The kingdom of Mitanni, which lasted from the early part of the fifteenth century, B. C., to the middle of the fourteenth, had as its first king Saushattar, the son of Parsashatar: A letter addressed to a local official at Nuzi and bearing his seal was found in the house of Shilwateshub.

Four groups of documents yield what little information we have about the Hurrian language: A letter of Tushratta, king of Mittani, to Amenophis III of Egypt (found at Tell el-Amarna in Egypt); a glossary and some texts found at Ras Shamra, near Latakiyeh; some tablets in the Hittite archives of Boghazkeui; and the tablets from Nuzi, written in Akkadian but containing occasional Hurrian words and thousands of Hurrian personal names.

The Hurrians that settled in the district of Arrapkha (Kirkuk) not long after 2000 B. C. organized a small kingdom that included the city of Ga-sur, renamed Nuzi by these Hurrian conquerors. One of the early Hurrian kings of Arrapkha was Itkhi-Teshub, the son of Kibi-Teshub. One of his inscriptions and three tablets bearing the impression of his seal have been found at Nuzi. He worshipped Teshub (Adad) and Ishtar of Lubdu. Two other kings mentioned in the tablets from Nuzi, Itkhiya, and Kirenzi may have followed

Itkhi-Teshub on the throne a considerable time later. Early in the fifteenth century, however, the district of Arrapkha, including Nuzi, became, with Saushshattar, an integral part of the kingdom of Mitanni. Apparently there never was a king of Nuzi, although sons of the king, like Shilwateshub, and "queens" resided there. The highest authority at Nuzi was the local governor, responsible at first to the king of Arrapkha and later to the king of Mitanni. A few tablets at Nuzi are dated according to the governors of the time. A governor named Kushshiharbe, according to a mass of specific testimony, was no less corrupt and high-handed than Verres.

The population of Nuzi was racially a mixture of Hurrians and Akkadians, and it remained bilingual, for Akkadian was the literary language and Hurrian the vernacular. At present, likewise, there are Turkomans, Kurds, and Arabs, speaking at least two of their three languages, living in the same region. The culture of Nuzi, however, is basically Hurrian, in spite of clear signs of Akkadian influence. The Hurrian invaders were on a much lower cultural level than the population of Ga-sur. Even though they made rapid progress after the conquest of the city, they never quite attained the refinement and elegance of the vanquished. The pottery and the figurines of Nuzi, for example, are decidedly cruder than those of Ga-sur. It is only in painting and in seal engraving that the Hurrians developed an artistic style of their own (pl. 2).

After the conquest the Hurrian leaders divided the land among their soldiers and established a feudal system in which the landowner was subject to the corvée and prevented from selling his land. The sale of a field could be effected legally only indirectly, by bequeathing it to the buyer after he had been adopted. Adoption for a price was a convenient device for other purposes as well: Free women were adopted for marriage to slaves or sons, occasionally even for sacred prostitution. Some persons, particularly childless widows and elderly couples, adopted a man of wealth, transferring to him at once all their possessions and obtaining in exchange a lifelong support and decorous burial at his expense.

Times of economic stress gradually deprived the small landowner of his holdings and even reduced him to the condition of a slave. Forced to borrow on the security of his land or of the person of his son, who served the creditor until the debt was repaid, the farmer would eventually be forced to adopt his creditor, thus depriving his family of the ancestral estate. The rich, in the words of Isaiah, "joined house to house and added field to field", whereas the poor were being sold into slavery, as Amos said, for the value of a pair of shoes. The middle class eked out a rather precarious existence in the various professions and skilled crafts on account of the competi-

tion of well-trained slaves, who, though they worked for their masters, were allowed to own property of their own and to engage in business on their own account. When a poor wretch in desperation dared to challenge the claims of his wealthy antagonist in a court of law he was confronted with well-authenticated contracts or affidavits and with oral testimony; defeated in his claims, he was not only obliged to fulfill his obligations but became liable for a pecuniary compensation. When no oral or written evidence was available, the judges had recourse to the ordeal, a prospect so terrifying to the poor that they instantly yielded to their antagonists on all points.

Polygamy was permitted but was not common. The number of concubines and slave wives was generally optional: a son of Tehiptilla, for instance, had 24 women in his harem. Some marriage contracts, however, specified that the wife would furnish a concubine to her husband only if she should be childless (exactly in the cases of Abraham and Jacob). At the death of the husband the widow held the estate (except for property previously deeded to a son) in trust for her sons. She could leave a few small items to a favorite son, in addition to his rightful share. If a widow remarried, she retained only her personal effects. Occasionally a widow inherited only movable property, of which she could dispose at will. The bridegroom paid to the father of the bride or, if he were dead, to her brothers a stated amount averaging 30 shekels of silver—the legal price of a slave. A portion of the bridal price was set aside as dowry for the bride. In the few recorded cases of divorce the husband took the initiative.

The chief deities of the Hurrians, at Nuzi and elsewhere, were Teshub, the Hittite weather god, and Ishtar. The two temples of Nuzi were in all probability dedicated to these deities, for there was in Nuzi a commander of the guard of the temples of Ishtar of Nineveh and of Teshub. Ishtar had several manifestations: she was Ishtar of Nineveh as consort of Teshub, Ishtar Humella as consort of Nergal, and Ishtar Dupkilkhe as consort of Sarie. The gods Bêl Ulamme and Zizae have consorts, but they are not named. The following gods of neighboring towns are known from tablets listing deliveries of oil to them: Ahulae, Azuihhe, Kumurra, Tilla, Tirwa, Zarwan; and also several other manifestations of Ishtar (I. Allaiwashwa, I. Bêlat-duri [mistress of the wall], I. Kubawa, I. Putahhe) as well as two Babylonian gods (Nergal and Shamash). Other Babylonian gods and two Hurrian gods (Til-Enlil and Har-Nuzu) are named in school exercises listing the sacred ships in which the divine images were carried in procession during the Babylonian New Year festival. A portion of a great Babylonian astrological treatise, hitherto known only through later and more corrupt copies, was

found at Nuzi. It deals with omens derived from earthquakes and begins with the words, "If the earth trembles in the month Nisan, the ruler's country will rebel against him."

Although the tablets from Nuzi make no direct reference to military operations, there are among them some reports on the inspection of troops and of weapons. The two main divisions of the army, the right and left flank, comprised chariotry, cavalry, and archery. Individual companies were under the command of an officer. A large tablet lists more than 2,500 men of various garrisons, belonging to various subdivisions of the army, who were demobilized. The inventories of military equipment enumerate weapons damaged or lost, either before or after the battle, and weapons removed from arsenals for delivery to officers. The war material listed in these reports comprises bows, quivers, and arrows; axes and adzes; trappings for horses; shields and spears; coats of mail for men and for horses. The complete breast piece of a coat of mail, made of copper scales sown on a leather jacket, and many isolated scales of various sizes, were found at Nuzi—the earliest examples of such defensive armor known to us. Some coats of mail, particularly those for horses, had leather scales.

The military organization and equipment of the Nuzians did not save their city from conquest and destruction. Soon after the end of the Kingdom of Mitanni about the middle of the fourteenth century, the Assyrians, presumably under Enlil-nirari (about 1340), or Adad-nirari I (about 1300), sacked and destroyed Nuzi with frightful ruthlessness, as shown by the condition of the ruins uncovered in the course of the excavations. Shortly before the fall of Nuzi, a grandson of Tehiptilla named Takku recorded with stolid objectivity the spoliation and deportation of the Hurrians of Tursha, a town not far from Nuzi; the Assyrians pursued them into the inhospitable recesses of the forests, enslaved the captives, and slew those that offered the slightest resistance. The fall of Tursha was but the prelude of the fall of Nuzi. Only a handful of Nuzian families, fortunate enough to escape the disaster, were bold enough to return to their city, rebuilding a few houses on its ruins. But this miserable remnant soon disappeared, and Yorghan Tepe, under which the forgotten city of Nuzi lay buried, forsaken by the few Parthian families who had settled on it for a time, became a Sassanian and Moslem cemetery—and eventually the grazing ground for sheep and goats.

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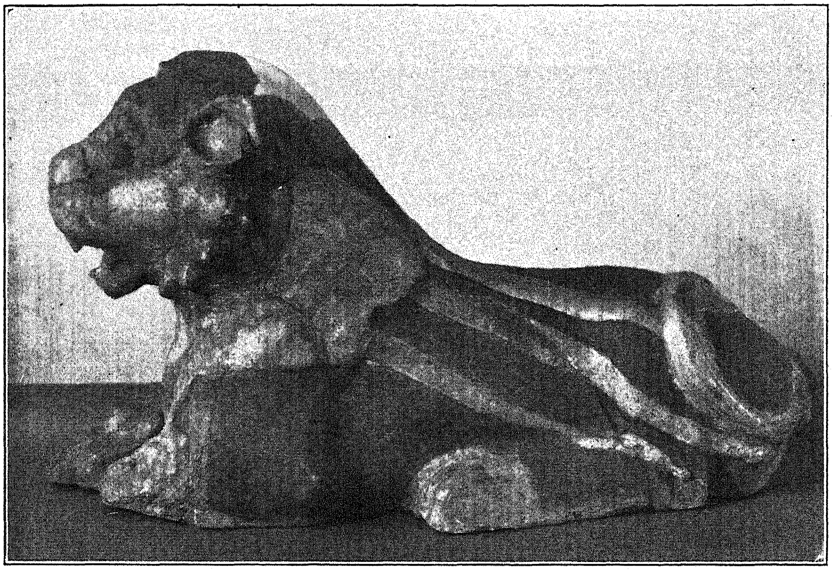
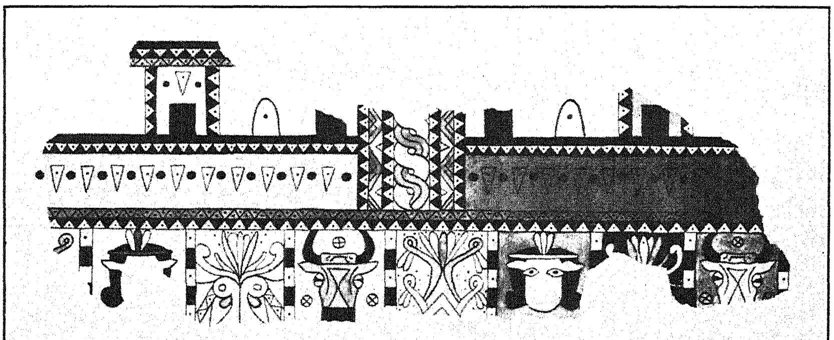
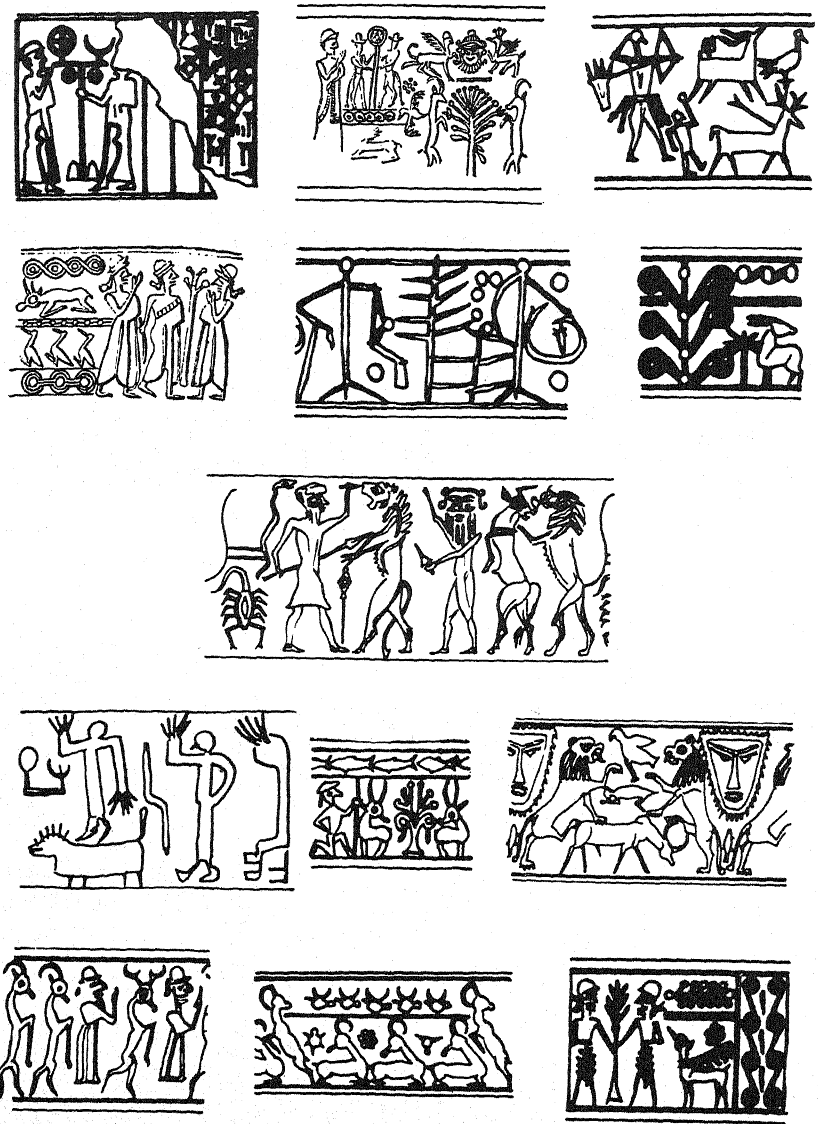


1. LION, GLAZED TERRA COTTA, FROM TEMPLE A.



2. SKETCH OF ONE OF THE FOUR FRAGMENTS OF FRESCOES FROM NUZI, ABOUT 1500 B. C.



IMPRESSIONS OF TYPICAL HURRIAN SEAL CYLINDERS FROM NUZI.

THE RUINS OF TENAMPUA, HONDURAS[1]

By Dorothy Hughes Popenoe

[With 5 plates]

INTRODUCTION

The traveler approaching Tegucigalpa, Honduras, over the excellent motor road that winds through the mountains from the southern end of Lake Yojoa will see upon his left, an hour after he leaves Comayagua, a flat-topped promontory which juts out menacingly from the pine-clad mountain range. Sentinellike, it watches over the ancient capital and its classic valley. This is Tenampua. It is the site of extensive ruins dating from pre-Columbian days and is reckoned among the major archeological treasures of Honduras. Obviously, the spot was chosen by the ancients for its military value. As a place of permanent residence it offers few attractions, for it has neither abundant water nor fertile soil; but as a stronghold to which the people might retire in times of danger it is well-nigh impregnable.

Early accounts of the struggle between the primitive inhabitants of Honduras and their Spanish conquerors contain numerous references to mountain fortresses such as this. To illustrate their importance in the general scheme of defense, I may be permitted to recite the following bit of history, gleaned from a letter which Francisco de Montejo addressed to the King of Spain. The date was June 1, 1539.

Disturbing news reached Gracias, where Montejo was sojourning with 11 Spanish soldiers. The Indians were preparing stubbornly to resist him. In Yamalá, a nearby village, "estavan faziendo muchas cases en un peñol muy fuerte que tienen e proveyéndolos de bastimentos."[2] The Spanish chieftain sent a Negro spy, who knew the language of the Indians, to enter the stronghold and bring back a report. The frightened Negro found there "quatro casas muy grandes hechas, y otras quatro mayores lienas de maíz, y pusoles fuego a las

[1] The author of this paper, Mrs. Dorothy Hughes Popenoe, died December 30, 1932. The present article is the original English version from which the article in Spanish, "Las Ruinas de Tenampua", Tipografia Nacional, Tegucigalpa, 1928, was translated. The illustrations and the text of the two articles differ slightly.

[2] Translation: "They were building many houses on a great, very strong rock which they have, and providing them with provisions."

casas y al maíz."[3] Word came of great disaster in the valley of Comayagua. The Indians had risen. One Spaniard had been killed and several others wounded. Four horses had been lost. Unable longer to withstand the siege, the Spaniards had fled at night to a neighboring province where the inhabitants were friendly.

Montejo realized that the time had come for desperate action. Supplies were brought together, and soldiers were called in from regions where the danger of rebellion was not imminent. Others who had been wounded but now had recovered sufficiently to join the colors augmented the small band which was placed under the leadership of Alonzo de Cáceres, recently returned from the final campaign against Lempira.

When they arrived at Comayagua they found that the Indians, doubtless apprised of their approach, with all available supplies "se fortaleciesen en peñoles."[4] Cattle which they could not take with them had been killed and eaten, so that the valley was now in a state of starvation.

Montejo advanced into one part of the valley, Cáceres into another, attacking and capturing a mountain fortress "que era el mas fuerte de aquella comarca."[5] The last-named leader then proceeded to a village, by name Guaxerequi, where six Christians had recently been killed. There he found another fortress. At this point he was rejoined by Montejo, who describes the place in his letter. He says:

> y visto el peñol, que era la cosa mas fuerte que se ha visto, que si tuvieran tiempo de cortar un cuchillo de sierra que estavan cortando era imposible tomarse, porque tenían dentro agua y leña e sementeras y muchos bastimentos, tenían doscientos e veinte casas grandes, y ciertos tempos e adoratorios.[6]

It took the combined forces of Montejo and Cáceres 4 months to conquer the valley of Comayagua, after which they carried the campaign into Olancho.

Such stories as the above throw much light on the importance of fortified mountain tops at the time of the Conquest. Although it has been impossible to place Tenampua among the strongholds described in the early accounts at my disposal, it seems probable that it may have been one of those captured during the campaign carried out in the Comayagua region by Francisco de Montejo and his lieutenant, Alonzo de Cáceres. It may have been the formidable Guaxerequi described in Montejo's letter.

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[3] Translation: "Four houses built very large, and four more larger ones full of corn, and he set fire to the houses and to the corn."

[4] Translation: "would fortify themselves on big rocks."

[5] Translation: "which was the strongest in that region."

[6] Translation: "And (has) seen (or visited) a great rock, which was the strongest thing that has been seen, which, if they had time to cut a ridge of mountain, which they were cutting, would be impossible to capture, for they had in it water and wood and cultivated fields and many provisions, they had 220 large houses, and certain temples and places of worship."

PREPARATIONS FOR STUDYING THE RUINS

Upon leaving Tela in July 1927, I proceeded direct to the city of Tegucigalpa, where, through the active interest of the Minister of Gobernacion y Justicia, Dr. José María Casco, permission to explore, excavate, and photograph the ruins was granted by his Excellency, President Miguel Paz Baraona.

I then returned to Comayagua, where I have to thank my good friends, the Señoritas Mercedes and Julia Castillo Medal, for their gracious hospitality during the time spent in preparing and outfitting for the work to be done. Don Carlos David kindly offered the use of a house in Flores. This village is situated a league and a half from the ruins, and it had originally been my intention to spend my nights there, returning to the ruins daily; but the considerable amount of time lost in this fashion, together with the fatigue following upon the climb of several hundred meters from the valley floor to the mountain top, caused me early to abandon the plan and to establish headquarters in a rude camp in the midst of the ruins.

Three weeks were spent in mapping, studying, and photographing, and in reconstructing several of the stairways and walls. During this period I had the constant and loyal assistance of Jorge Benites, whose intelligence and efficiency were invaluable.

PREVIOUS ARCHEOLOGICAL RESEARCH

The first authentic account of this site which has come to my notice is contained in a letter written by the learned and brilliant E. G. Squier to the Historical Society of New York. This was sent, in the year 1853, from the city of Comayagua, and was later published.

Five years after this, Squier published a more complete description of the site in his well-known work entitled "Notes on Central America, Particularly the States of Honduras and Salvador." It is to be regretted that he included no maps, diagrams, or sketches, so that the reader fails to receive a graphic picture of the ruins.

H. H. Bancroft, in his work entitled "Native Races of the Pacific Coast" (1875–76) attempted, perhaps, to remedy this deficiency, for he prepared a diagram of the Central Enclosure based upon Squier's description. I am informed by H. J. Spinden that this diagram (which I have not personally seen) is not accurate.

In 1916–17 the Peabody Museum of Harvard University sent an archeological expedition to Central America, in charge of S. K. Lothrop. This party visited Tenampua and mapped the entire mountain top. Their complete report has not been published, but a section of the map, showing the Central Enclosure and the Parallel Structure appeared in a general account of the expedition which was published in Indian Notes, Museum of the American Indian, New York City, volume 4, 1927.

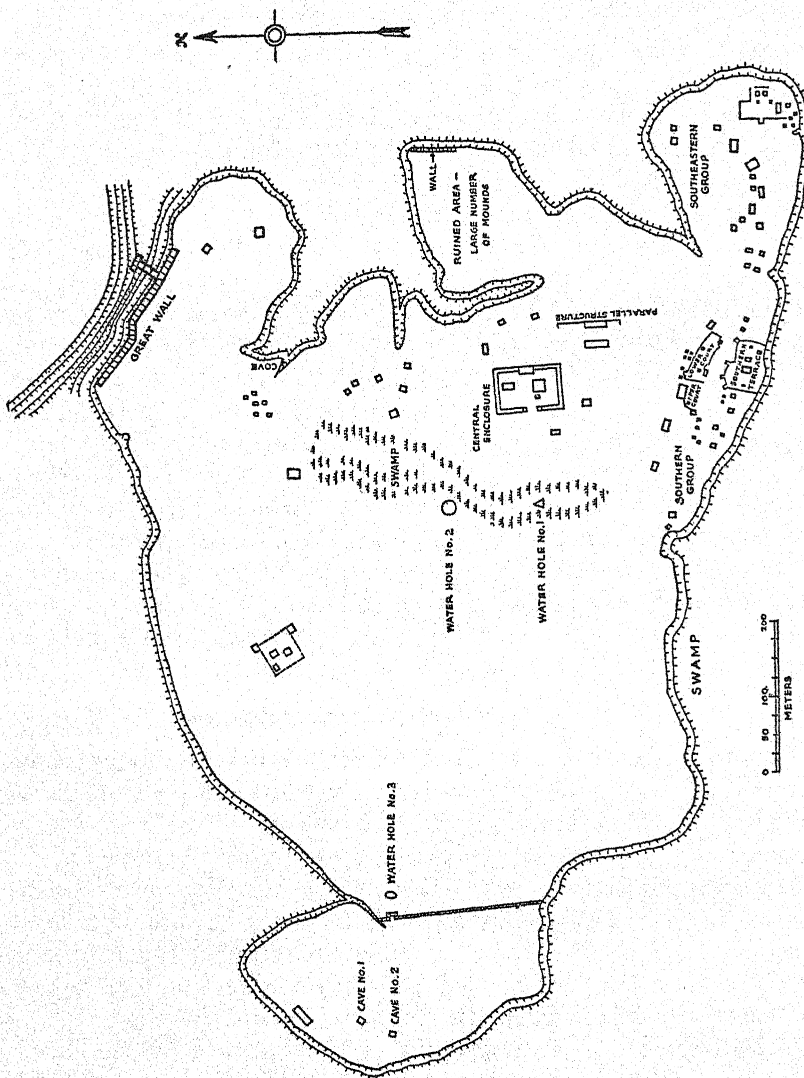


FIGURE 1.—Sketch map showing principal structures.

THE FORTIFICATIONS OF TENAMPUA

From a strategic standpoint there is only one weak spot in the natural defenses of Tenampua (map, fig. 1). This is the narrow ridge on the northeast side which connects the promontory with the neighboring range, and which has already been suggested as the "cuchillo" mentioned by Montejo in his description of Guaxeregui.

Near this ridge are the remains of strong artificial fortifications. A great wall, 225 meters long, in places crumbled to the ground, in others 3 meters high and 8 meters thick, blocks this natural access to

the plateau. Jutting out from the center of this wall and extending down the hillside at right angles to it is a second wall 22 meters in length, terminating in a buttress 5 meters in thickness.

The usefulness of the main wall in enabling the defenders to repulse an enemy which might attempt to cross the narrow causeway is obvious. Not so clear is the purpose of the extension down the hillside. Below the buttress is the actual separation between the two mountains, consisting of a deep barranca formed originally by the action of water. I climbed to the bottom of this barranca and examined both sides carefully. The upper slopes are evidently natural, but there is a vertical cut immediately above the stream, 6 meters in depth on both sides, which has the appearance of being artificial in origin, or at least finished artificially to strengthen the defenses.

The walls are not particularly well built. They are made of broken rock. The fragments are more or less uniform in size, approximately 45 to 60 centimeters in diameter, and are piled against one another without any suggestion of breaking joints. The interstices are chinked with mud.

Evidences of superimposed construction, probably dating from a much later period than the original wall, are seen in several places. They consist of gaps filled with newly broken stone without mud chinking. These portions contrast strongly with the moss-covered and weather-worn face of the original wall. It seems probable that they are the work of modern armies. Gen. Vicente Tosta, during the campaign of 1924, is said to have stationed troops at this spot for several weeks.

On the extreme edge of the plateau is another wall. This is smaller but of similar construction. Except for these two artificial defenses, the plateau is almost perfectly protected by the natural cliff, which drops away on all sides to merge with the valley floor some 300 meters below.

THE WATER SUPPLY

All that can now be seen of the ruins are numerous mounds and terraces overgrown with pine woods and grass. Great roots of fast-growing trees are tearing apart the steps and stone facings; grazing cattle roam over the site and further the work of destruction.

It is to be assumed that this spot served in ancient times not only as a fortress to be held against attack, but also as a refuge for the entire populace of nearby towns and villages.

In addition to adequate defenses on all sides, Tenampua would need, therefore, a water supply sufficient to meet the requirements of a siege.

The principal ruins are clustered upon the southeastern corner of the plateau. To the west is a large depression in the rock surface,

where rain water collects and a swampy area has formed. In the center of this are two pits overgrown with weeds; these may have been used as water holes by the ancients, though it is also possible that they may have been opened in more recent times. One of these holes is triangular in outline, the other circular. Both measure, roughly, 30 meters across. They are only half a meter in depth.

In addition to this meager supply, additional water can at times be obtained from three ravines which drain the eastern part of the plateau. But these carry only tiny rivulets, which go tumbling over the edge of the precipice to lose themselves in the valley below. Along their courses toward the edge of the plateau, nances and live-oaks arch overhead. Squirrels and humming birds abound. Wild frangipani grows down the cliffs, its waxy blossoms gleaming white against the pines above.

Unless the supply was far greater in the time of the Lencas, it is difficult to imagine how the small quantity of water available upon the plateau could have sufficed for the many people who must have stayed at Tenampua during times of siege.

THE CENTRAL ENCLOSURE

During our stay we camped on a mound in the Central Enclosure. Advantage was taken of an excavation made by previous visitors; above this we constructed a rude shelter of ponchos and pine boughs.

In general plan, the Central Enclosure (which Squier considered to be the most important group at Tenampua) agrees with at least three other groups (pl. 1, fig. 1). This uniformity would suggest a religious basis.

Each of these major groups possesses a platform or terrace, large and oblong in outline. A wall surrounds this, or, if the situation warrants, a flight of steps leads up to it. Surmounting the platform, and placed side by side, are two large mounds of different sizes. Close by is a third mound, scarcely more than 30 centimeters high, and edged with stones. The stairway leading to the summit of the larger mound suggests that it was originally occupied by a building of some sort—probably a temple.

The general arrangement of the major groups recalls the writings of the historian Oviedo, who describes the religious practices of the ancient Costa Ricans. There, wooden temples were built within courts or patios; each was dedicated to an idol of wood or clay, which was usually kept in a small house within the patio. The center of the enclosure was occupied by a mound where sacrifices were made. Women danced around the mound before the commencement of a sacrificial ceremony.

The wall surrounding the Central Enclosure is so badly broken down that it was impossible for us to determine its construction without excavation. This was commenced at the southwest corner. We found a central core of soil, faced on both sides with roughly cut stone, and traversed at irregular intervals by low stone partitions. The thickness of the wall is approximately 4.5 meters. Its height above the ground is about 1 meter on the outside, somewhat less on the inner surfaces toward the patio, owing to the fact the latter has been raised some 35 centimeters above the general level.

Excavation of one corner of the patio to the level of the outside ground showed it to be built up of ordinary soil. Outside the wall, and surrounding it at a distance of about 1 meter, is a low line of stones, in many places broken away. This may mark the edge of a low outer terrace, now obliterated.

As the work of cleaning and excavating progressed, I came to the conclusion that the builders of Tenampua were neither great architects nor accurate workmen. We took measurements of this wall and found that the eastern side (approximately 84 meters in length) exceeds the western by some 4½ meters. The southern side is 1¾ meters longer than the northern.

The large mound is about 3½ meters in height, and 21 by 15½ meters at the base. Its internal structure was partly disclosed by the excavation in which we built our camp. To complete the work we drove a shaft from the summit through the center. The lower and middle layers were found to be composed of topsoil scraped, undoubtedly, from the neighboring ground; above this, and on the sides, we found a layer of broken rock faced with stone. The remnants of three terraces are barely visible on this mound.

The scanty remains of the stairway were cleaned and restored. The stone slabs which formerly served as steps are poorly cut and of varying sizes. The fact that they are now sadly out of line is due, no doubt, to the pressure of pine roots. A large tree has grown from the very summit of this mound.

While digging the shaft, parts of two pottery dishes came to light. The first had been a spherical jug, unpainted, with four circular handles at the mouth. It may have had originally a neck or spout, for the top opening, though small, has a broken edge lacking any vestige of a rim—the part that usually survives.

The second specimen, also broken and lacking several pieces, is of exceptional beauty. It is a shallow dish, 23 centimeters in diameter, supported by three stout legs. A reconstructed drawing is here presented (fig. 2). The original is painted in three colors—cream, a warm brick-red, and dark brown.

THE PARALLEL STRUCTURE

This was described by Squier, and more recently S. K. Lothrop has published a plan (Indian Notes, vol. 4, 1927). Both these authorities are of the opinion that we have here the remains of a ball court, comparable to those used by the Mayas and Aztecs.

The structure is composed of two parallel mounds, each 30 meters in length; they stand upon a low terrace, with a level open space 11 meters wide between them. On their inner sides the mounds are faced with stone slabs 1 meter in height and 40 to 50 centimeters wide.

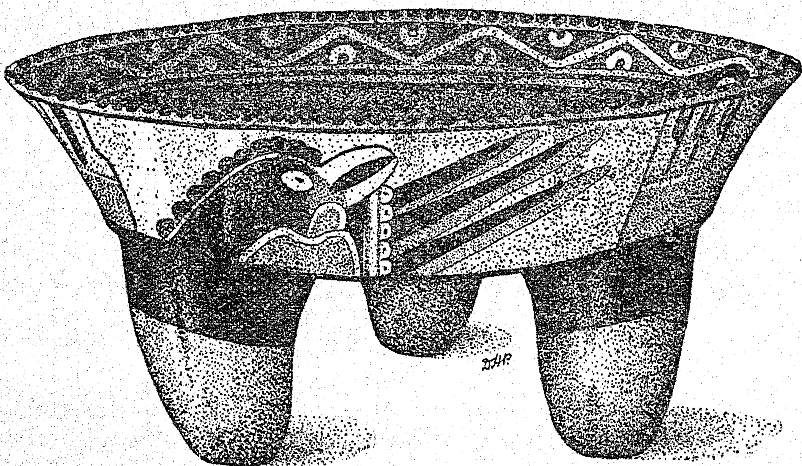


FIGURE 2.—Clay vessel (reconstructed) from the principal mound in the Central Enclosure. The decoration is in three colors, cream, brick red, and dark brown.

THE SOUTHERN GROUP

Though Squier considered the Central Enclosure the most important unit of Tenampua, to me the Southern Group seems to merit this distinction (map, fig. 3). Its chief characteristic is a sunken court or plaza approximately 115 meters long by 30 wide, which a low stone wall divides into 2 parts, 1 at a slightly lower level than the other (about 1 meter). A number of small mounds, irregularly arranged, dot the lower court. Seven steps lead from the upper court—the floor of which is level and devoid of mounds—to the level of the platform (pl. 1, fig. 2).

The Southern Terrace, a raised platform 30 meters long and nearly 10 meters high, rises from the southern part of the lower court (pl. 2, fig. 1). It stands at the very edge of the plateau and commands a magnificent view over the valley of Comayagua lying far below. On its summit are four mounds arranged after the same fashion as those of the Central Enclosure; the largest, 10 meters square by 3 meters

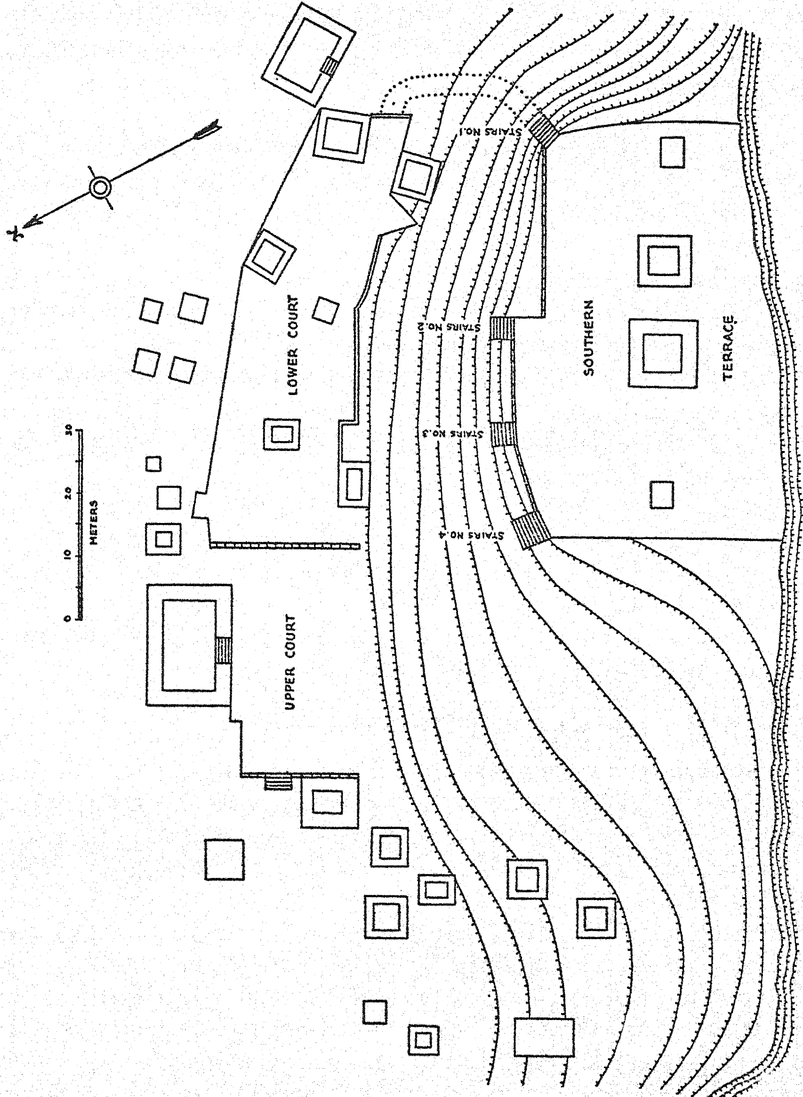


FIGURE 3.—Sketch map of the Southern Group, showing principal mounds and stairways.

high (pl. 2, fig. 2), corresponds to the "temple" mound of the latter and has a smaller mound immediately to the east. The remaining two mounds are low (about 4 meters square) and edged with stones.

Squier suggested that it might have been the custom in ancient days to light beacon fires on the highest mound of this group for the purpose of signaling to people in the valley. There are no ashes or other evidence that such was the case. The mound consists of broken rocks roughly heaped together, covered with a thin layer of humus.

The surface of the Southern Terrace has been paved, in part, with flat stones. Along its northern edge are to be seen the remains of a low wall and 4 stairways, 3 of which extend a short way down the slope, while the fourth (at the northeast corner) has nine steps which terminate in a flagged walk bordered by mounds, leading directly to the lower court (pl. 3, fig. 1). This stairway and two others were restored by us.

The north side of the same court is provided with two series of steps leading up to the general level of the plateau. The eastern series is extended to form a narrow paved walk exactly in line with the distant parallel mounds of the so-called "Ball Court."

On the northern side of the upper court is a large oblong mound. The stairway which ascends this terminates abruptly at the foot of a vertical wall 2 feet high. Above this, the surface is cobbled with rows or rounded stones set on end.

Judging by the height of the wall and the presence of these stones, it seems unlikely that this platform was originally surmounted by a temple or other building. Perhaps it was an altar. Praying for victory over the strange new enemy from across the sea, perhaps the fighting Lencas climbed these steps 400 years ago, carrying sacrifices to place upon the rugged platform.

THE SOUTHEASTERN GROUP

The Southeastern Group was described briefly by Squier, but his account does not adequately cover the material as it exists today. Though he mentions a surrounding wall similar to that of the Central Enclosure, I was unable to find vestiges of such a structure (maps, figs. 1 and 3).

Near the edge of the cliff are two mounds similar to those of the Southern Terrace. The larger of these is slightly less than 2 meters high, and stands upon a terrace edged with stone and elevated to a height of 3 meters. Two curious structures are to be seen close by these mounds; they are low, circular hillocks scarcely more than 12 centimeters high, covered completely with large flat stones. A third object of this character lies a few meters to the northeast, below the terrace and almost at the edge of the cliff. A fourth occurs due west of this in a straight line with the western wall of the terrace. As will be seen in the map (fig. 3), there are other mounds, some of them large, between this group and the Southern Terrace.

The most interesting single object encountered during the course of our explorations was an elaborately carved metate found in one of the mounds of the Southeastern Group. This specimen, represented in figure 4, is made of basalt. Though one leg was broken at the time

it was excavated, sufficient fragments were recovered to show that the design is different on the two sides.

OTHER ARTIFACTS

Scattered throughout the ruins are many fragments of plain stone metates of the type used today in Central America (pl. 3, fig. 2). No unbroken ones were seen; but if such had been left by the ancients, they would almost certainly have been carried away by modern inhabitants of the region to use in their homes. Some of these metates had thick, short feet; others none. All were made of a coarse red sandstone which does not occur naturally at Tenampua.

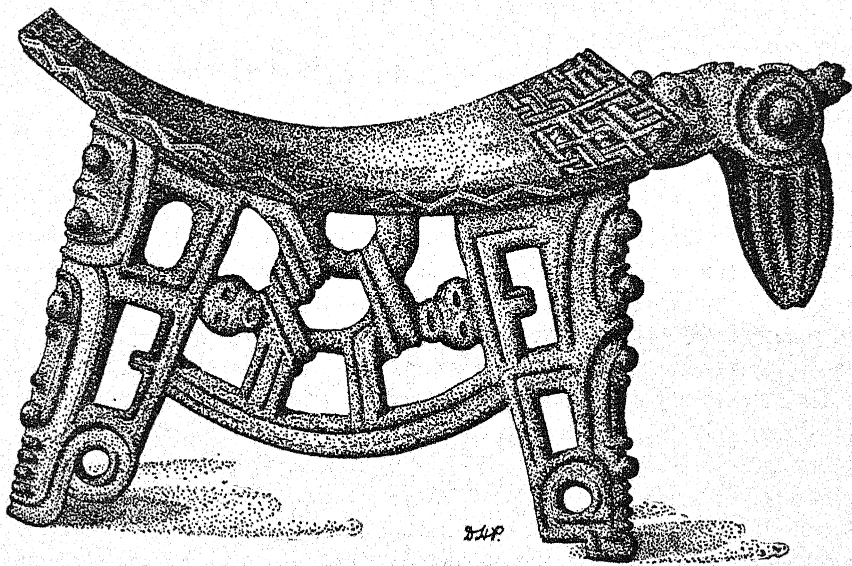


FIGURE 4.—Curiously carved stone metate encountered in one of the mounds of the Southeastern Group.

We also found fragments of another form of milling stone made of a finer grade of sandstone. This was flat, oval in shape, about 25 centimeters in greatest diameter, and 10 centimeters thick. From the marks left upon it, we could ascertain that it had been used on edge, vertically, the two sides having been held in the hands.

Red sandstone balls, more or less uniform in size and weighing from 1½ to 2 kilograms, were found in various places. These suggest stones which have been rounded and smoothed by the action of running water, most probably in a river bed. They do not seem to occur naturally in this region but may have been carried here for throwing or slinging at the enemy. Their shape and size are such as to make them fit conveniently into a man's hand.

Seeking evidence as to their use, I examined the whole of the mountainside below the southern group, where some of these stones, and a quantity of obsidian chips had been observed. The first third of the descent toward the valley floor was strewn with fragments of pottery, chips of obsidian, and roughly chipped flint and obsidian spearheads. Below, I ceased to find these but came upon numerous sandstone balls. The remainder of the descent yielded nothing, as it was covered with a thick layer of broken rock which had fallen in recent times, apparently, from the cliff above.

THE CAVES

A description of Tenampua would not be complete without reference to the caves. All sorts of legends and superstitions are connected with them. He who enters must expect to encounter ghosts, coyotes, demons, spells; nothing is too dreadful to be found there.

Squier knew of two, situated near the northwest corner of the plateau. The locations are clearly visible from a distance, since each is surrounded by a tangle of junglelike growth, contrasting with the uniform and temperate-zone appearance of the grass and pines which characterize this region. Cutting our way through the thorn acacias and lianas which surround the entrance to the more northerly cave, Jorge and I came upon a large hole in the ground. It was more or less circular in outline, 6 meters across and 5 meters deep. It had the appearance of being artificial. The bottom was filled with semidecayed leaves and broken rock, which had almost covered an opening at the north side. It is believed, locally, that this opening marks the entrance to a tunnel which leads through the mountain; thence under the valley floor; to come out finally in a distant range of mountains, at a ruined site known as Chapuluca or Chapulistagua.

After clearing away the fallen leaves and rock we found the passage completely blocked. Slabs of stone had fallen from the roof. An opening 2½ meters wide and 1¼ deep was cleared (this measurement is not the true height, as we did not remove all the debris from the floor) (pl. 5, fig. 2). Numbers of frightened bats flew out into the dazzling daylight, and circled around our heads or hung on the branches of the trees awaiting the first opportunity to return to their ancient home. Three meters of passageway were cleared of rock. Then the direction changed. So far, the tunnel had run in a northerly direction and slightly downward. Now, it narrowed suddenly to a width of no more than a meter and turned sharply to run vertically into the earth. The work became all but impossible. "Uncomfortable" Jorge expressed it, cramped and crouching on his knees, digging out the rocks one by one with a hand trowel. The

persevering boy excavated another meter; then we gave up. Whether the tunnel was built by the Indians as a means of escape in time of defeat, or whether it is an old mining shaft I am unable to say. We searched the mountainside toward which the passage leads, but found no opening.

We did not attempt any work in the similar cave lying some meters to the south. Besides this one, there are at least two other caves at Tenampua. One opens out of the wall on the east side of the plateau; the other is situated in the cliff just below the Southern Terrace. Both were entered, and they impressed us as natural formations.

SUMMARY AND CONCLUSIONS

Tenampua is a rocky promontory rising from the southern edge of the valley of Comayagua. It is a natural stronghold, protected on all sides by steep cliffs, except where a narrow hog-back ("cuchillo") joins it to the adjacent mountain range. Early accounts prove that numerous fortresses of this type were utilized by the aboriginal inhabitants in their struggle against the Spaniards.

Judging from its locality and physical characteristics, it seems possible that Tenampua may be the Guaxeregui described by Francisco de Montejo, one of the Conquistadores. There is little evidence to suggest the date at which the site was first occupied. The archeological remains now visible, however, probably date from a period shortly before and extending down to the Conquest.

From early Spanish accounts we learn that the aboriginal inhabitants of the Comayagua Valley called themselves Lencas. Their language and customs were different from those of neighboring tribes.

The name Lenca was first applied scientifically to this ethnic group by E. G. Squier about the middle of the last century. It is still considered uncertain whether these people were derived from one of the great linguistic stocks (Maya and Nahuatl) which occupied the territory to the northward or whether they constituted the vanguard of a migration from the south. The investigations at Tenampua reported in this paper tend to strengthen the latter belief. It is to be assumed, however, that the Lencas felt the influence of their more highly civilized neighbors on the north.

Comparison of the brief vocabularies at my disposal fails to reveal any relationship between Lencan, on the one hand, and either Maya or Nahuatl, on the other. As indicated by the following table, the similarity between Lencan and the Chibchan dialects of Costa Rica, and in a few instances between Lencan and the true Chibcha of Colombia, is sufficiently close to suggest that all may have been derived from the same linguistic stock.

TABLE 1.—*Comparison between words in Lencan and other languages*

[Compiled from Squier, Carlos Gagini, Vicente Restrepo, and other authorities]

Words	Honduras	Nicaragua		Costa Rica		Colombia
	Lencan	Subtiaban [a]	Ulvan	Chiapanecan Dirian	Chibchan 1, Guatuso; 2, Guetare; 3, Talamanca; 4, Guaymie; 5, Doraskean	Chibcha
ant	sisi				zifi (1) si, tsa (3)	ize
fire	yuga, yuca	ahku	cuh	nahu	yoco (2) iuk (3) nugo (4)	gata
hair	asa, asha	tu'su		nembe	iza (1)	ibsa
heart	mussu	buneo		nambooma	mazutu (1) kuy-si (3)	puy-kuy
house	tahü, taco	güah	ū	nahngu	uh (1) tu (2) u, uh (3, 4, 5)	güe
maize	ama	eshe, ehpe		nahma	ep (3)	aba
man	taho, amashe	rahpa	all	nuho	pejelilli (2)	
mother	mini, imini	autu		goomo	me (3) ti-me (4)	
snake	salalá, salá	apu	maabka	nule	zalan (1)	
star	siri	ucu		nuete	siyon	
tooth	nagha, nee-aa, née	sému		nehe	oka (1) saka (2) kasa, aka (3)	sica
one (numeral)	ita, eta	imba		teka	etzi, et (3)	ta, ata
water	guass, uash	eeia	wass	nimbu	ti dicre (2) ti (3, 4)	sie

[a] Nagrandan of Squier.

The artifacts brought to light during the explorations of which this paper is a report are not characteristic of Maya culture. The painted dish (fig. 2) is similar in style to pottery found throughout Central America. It has none of the features that distinguish Maya pottery from that of other races.

The carved metate (fig. 4) strongly suggests, both in design and workmanship, countries lying to the south of Honduras. In Leon, Nicaragua, according to Squier, such metates are not uncommon. One figured in his work entitled "Nicaragua: People, Scenery, Monuments, etc.", is of this type. Numerous specimens excavated in the peninsula of Nicoya, Costa Rica, were figured by C. V. Hartman. From that country southward, these metates occur in more or less modified form as far as Ecuador.

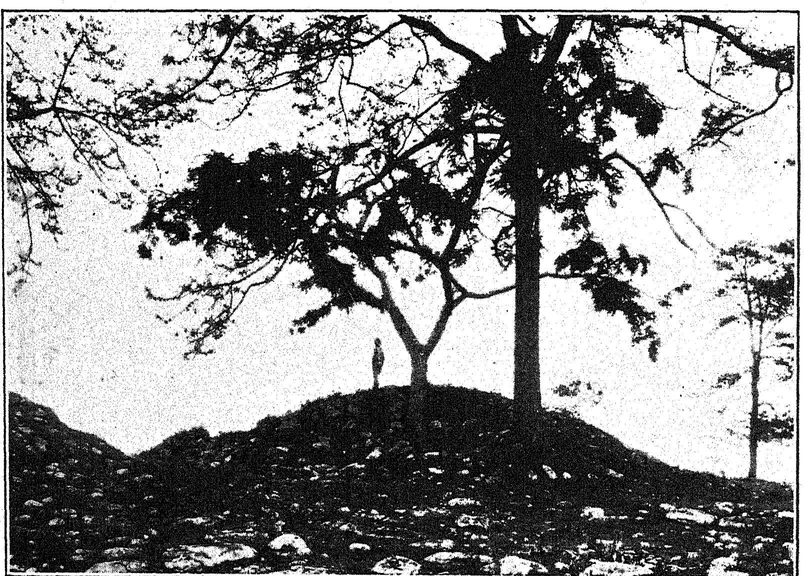
The inscriptions observed at Tenampua are rude and primitive in character (examples are shown in pl. 4, fig. 2, and pl. 5, fig. 1). Their significance is not clear to me. (Later, Mrs. Popenoe came to the conclusion that certain of these might have been made by the soldiers of General Tosta and other recent visitors sharpening machetes.) They are similar to markings observed on large stones lying on a hillside near Siguatepeque.

There remain many ruined sites in Honduras which have not yet received adequate attention at the hands of archeologists and ethnologists. Thorough investigation of these sites will not only throw much light upon Honduranean archeology in general, but will furnish specific facts to help clear away the doubts in which certain problems of Tenampua are still enveloped. It is only through comprehensive study of the entire field, and intelligent comparison and correlation of the material offered by individual sites, that the whole story of pre-Columbian Honduras will finally be reconstructed.

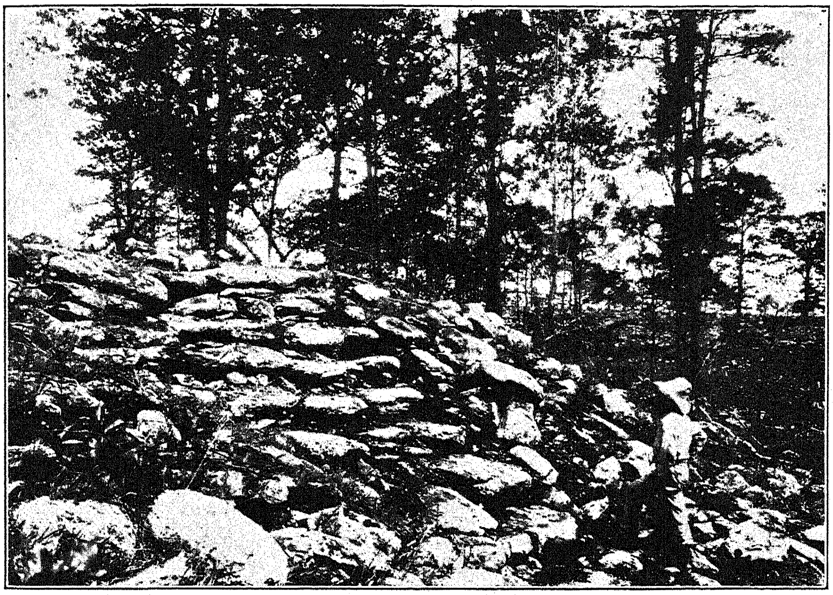
1. VIEW OF CENTRAL ENCLOSURE LOOKING EAST.

2. THE SUNKEN COURT, SOUTHERN GROUP

1. THE SOUTHERN TERRACE, SEEN FROM THE SUNKEN COURT.

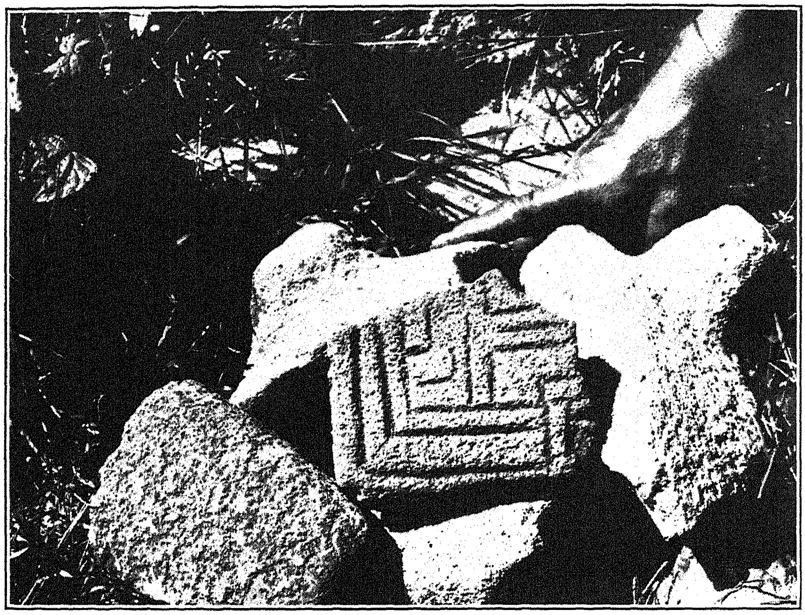


2. THE PRINCIPAL MOUND, SOUTHERN TERRACE.

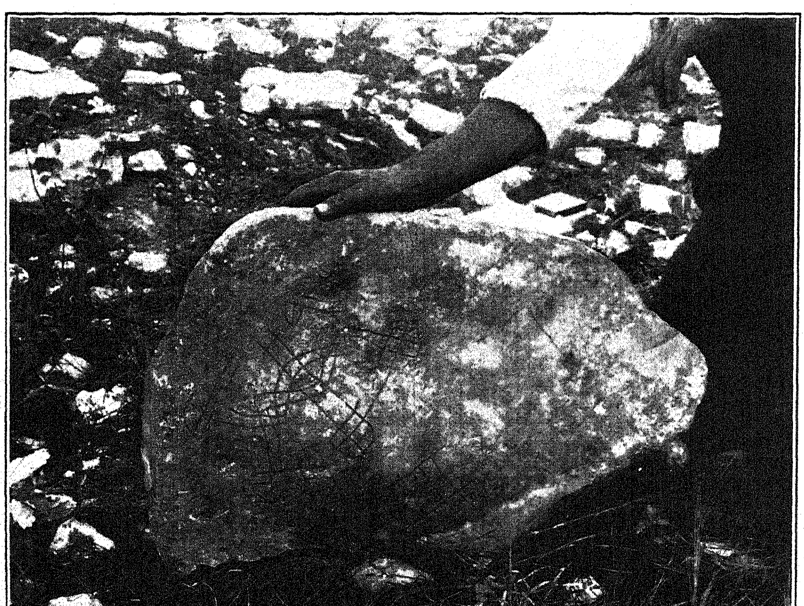


1. STAIRWAY NO. 1, RESTORED. SOUTHERN TERRACE, EASTERN SIDE.

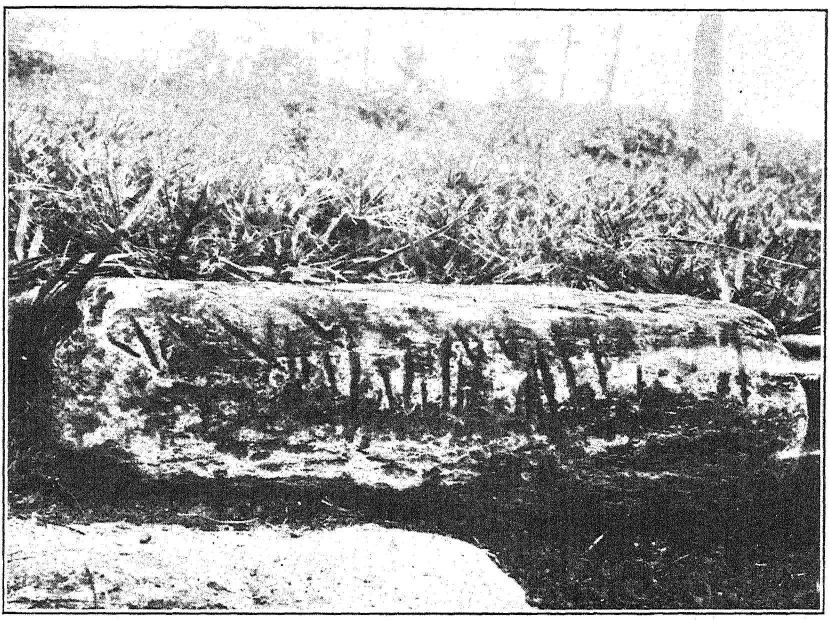
2. BROKEN METATES (MILLING STONES) FOUND AT TENAMPUA.



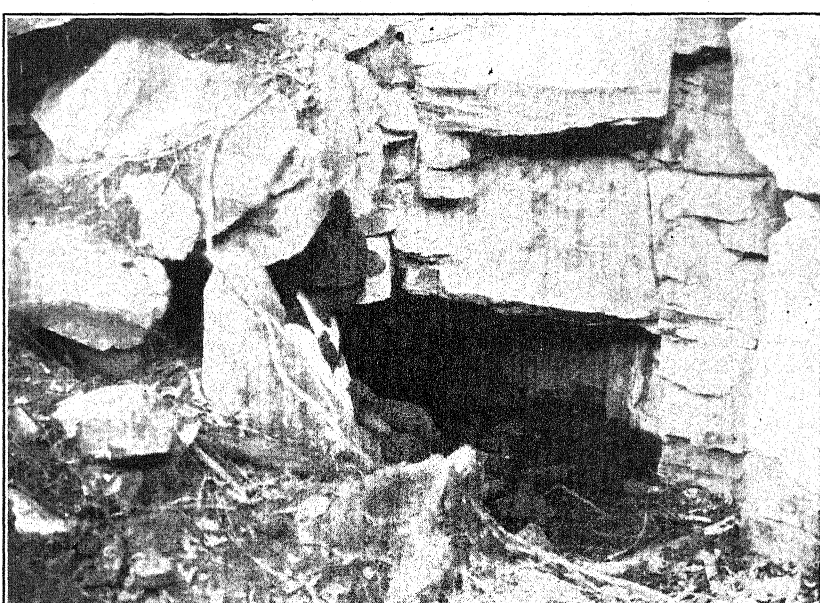
1. FRAGMENT OF WORKED STONES, PROBABLY PART OF A METATE.



2. INSCRIBED STONE (TABLET F) FOUND IN THE NORTHERN PART OF THE RUINS.



1. Inscribed Stone (Tablet A) in Upper Step of Stairway.



2. Partly Excavated Entrance to One of the Caves in Tenampua.

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